Westinghouse Technology Manual

Section 11.1

Steam Generator Water Level Control System

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11.1 STEAM GENERATOR WATER LEVEL CONTROL SYSTEM

Learning Objectives:

1. List the purpose of the steam generator water level control system.

2. Briefly explain how the purpose is accomplished.

3. List the reactor protection system inputs and turbine trip signals provided by the steam generator water level control instruments and the purpose of each.

4. List the inputs to the steam generator water level control system and the reason each input is necessary.

5. Describe why feed pump speed is programmed.

11.1.1 Introduction

Each steam generator has a three element control system to control the water level in that steam generator. The three elements used are steam flow, feedwater flow, and level error. The level is controlled by adjusting the feedwater flow with a control valve.

11.1.2 System Description

The purpose of the steam generator water level control system is to provide automatic control of steam generator water from 15 to 100 percent power. This control is the result of a three element controller which senses steam flow, feedwater flow, and a steam generator level error signal. There is one controller for each steam generator (Figure 11.1-1).

The steam flow is sensed by a differential pressure cell and corrected for density by a steam pressure detector. The resulting steam flow signal is fed to a summer. A flow error signal is produced by subtracting the feed flow signal from the steam flow signal. The flow error signal goes to a proportional plus integral (PI) controller.

The level program receives an input from the turbine impulse pressure transmitter. The impulse pressure signal can be conditioned to provide a proportional gain signal which will change level program as a function of power level. Actual steam generator level is sent through a lag circuit to dampen out natural oscillations in the level signal. A level error signal is produced by subtracting actual level from programmed level. The level error signal is sent to the PI controller. This PI controller allows level error to dominate the flow error signal. It also eliminates steady state level and flow errors. The level and flow error signals are added to produce a total error signal. This total error signal is the output of the PI controller when it is in auto. The output of the controller can be manually controlled by the operator. The output of the controller then goes to the current to pneumatic (I/P) converter to position the feedwater valve.

During a load change, steam flow and level both change, but the control actions would be opposite. For example, on a load increase, steam flow will increase, which by itself would produce a feedwater flow increase. But a load increase causes a "swell" or increase in level, which by itself would produce a decrease in feedwater flow.

The "swell" effect is only temporary. However, it would cause the level error portion of the control system to decrease feed flow, when in fact, an increase in feed is required to keep up with the increased steam flow. This "wrong way" response by level error is the reason for the "lag" or delay unit imposed on level error. It will delay the signal during the "swell" and allow the steam flow/feedwater flow error to increase the feedwater flow. After the "swell" clears and the level signal gets through the lag unit, the level error signal will help bring the level back to program level. A load decrease will cause a "shrink" or decrease in the level, and an opposite but similar response will occur in the level control system.

11.1.2.1 Level Instrument Channels

Steam generator level is measured in the downcomer region of the steam generator by differential pressure detectors which compare the downcomer levels to level in a "reference" or static leg. The narrow range channels measure only the top 8 feet of the 64 foot steam generator downcomer.

There are three narrow range level channels on each steam generator. They are used to generate a turbine trip and feedwater isolation when two of the three channels indicate 78% level on any steam generator. There is a reactor trip when two of the three channels indicate 21% on any steam generator. Two of the three channels are used in coincidence with a signal indicating steam flow greater than feed flow to initiate a 25% level trip. These reactor trips are discussed in Chapter 12, Reactor Protection System. A single wide range channel that measures the full downcomer level is used only for indication.

11.1.2.2 Turbine Impulse Pressure

One of the two turbine impulse (first stage) pressure channels is used to generate a reference level signal. Turbine first stage pressure is proportional to power, and steam generator level is programmed according to power. From no-load to 20% power, the level is programmed from 33% to 44%. From 20% to 100% power, program level is 44%. The 33% level at no-load conditions will limit the severity of a steam break accident when the water is most dense. As power is increased, it is desirable to increase level to maintain the mass in the steam generator as density decreases. A higher level also allows the plant to accept load decreases without shrinking to the low-low level reactor trip setpoint. The increase in program level is stopped at 20% power and 44% level to maintain high steam quality at the steam generator exit.

11.1.2.3 Feed Flow Channels

Bernoulli's equation shows that volumetric flow rate is proportional to the square root of the differential pressure across a venturi or flow orifice. To measure feed flow, a venturi is placed in the feed piping just downstream of each feed control valve. The venturi has two upstream pressure taps and two downstream pressure taps. Two differential pressure detectors are connected to these taps to give two separate channels of differential pressure measurement across the venturi. These differential pressure measurements are then sent to instrumentation to derive the square root and convert the signal to a feed flow rate signal.

11.1.2.4 Steam Flow Channels

The measure of steam flow is more difficult than feed flow because steam cannot be considered an incompressible fluid as can water. Therefore, the differential pressure signal must be corrected for changes in the fluid density as it passes through the nozzle. Because steam is a saturated vapor, changes in the steam pressure can be directly related to the fluid density change. Therefore, steam pressure is used to provide a density compensation signal to the steam flow instrument.

The steam generator flow restrictor is used to create a steam flow differential pressure. The differential pressure is sensed by two differential pressure detectors. These differential pressure detectors are independent and share their upstream taps with two narrow range level upper taps. The instrumentation takes the output of the detectors and derives the square root of the differential pressure and then density compensates the result to give steam mass flow rate.

11.1.2.5 Pressure Detectors

Steam pressure is measured just outside containment, upstream of the main steam isolation valve. There are four detectors for each steam generator. One of these has no other function than to control the atmospheric relief valve. The other three are protection channels used to provide inputs for the high steam line P safety injection signal, the low steam pressure coincidence for the high steam flow safety injection signal, and density compensation for the steam flow signal used in the steam generator water level control system.

11.1.3 Feed Pump Speed Control

Feed pump speed is controlled in order to allow the level control valves to operate at their optimum position (approximately half open) over the full range of required feed flow rates. This system will take the combined steam flow from all steam generators and generate a program differential pressure (Figure 11.1-2). It will then compare actual differential pressure (the difference between feedwater header pressure and steam header pressure) with the program differential. The error will cause the feed pump steam supply valve to change pump speed. Changing pump speed causes feed header pressure to change. Feedwater pressure is measured on the common header upstream of the feedwater control valves, and the steam header pressure is measured on the common header downstream of the main steam isolation valves. By programming pump speed, the feedwater control valves can be kept near the middle valve position where it has the best flow control characteristics. Feed pump speed control changes are slow enough to allow principal control of feed rate to be accomplished by the steam generator water level control system.

11.1.4 Summary

Water level in each steam generator is controlled by a system that monitors steam flow, feedwater flow, actual level, and program level. Control of the level is accomplished by controlling feedwater flow with a flow control valve. The pressure drop across the flow control valve is programmed to keep the valve in its middle range for good control. The differential pressure is controlled by varying feedwater pump speed.

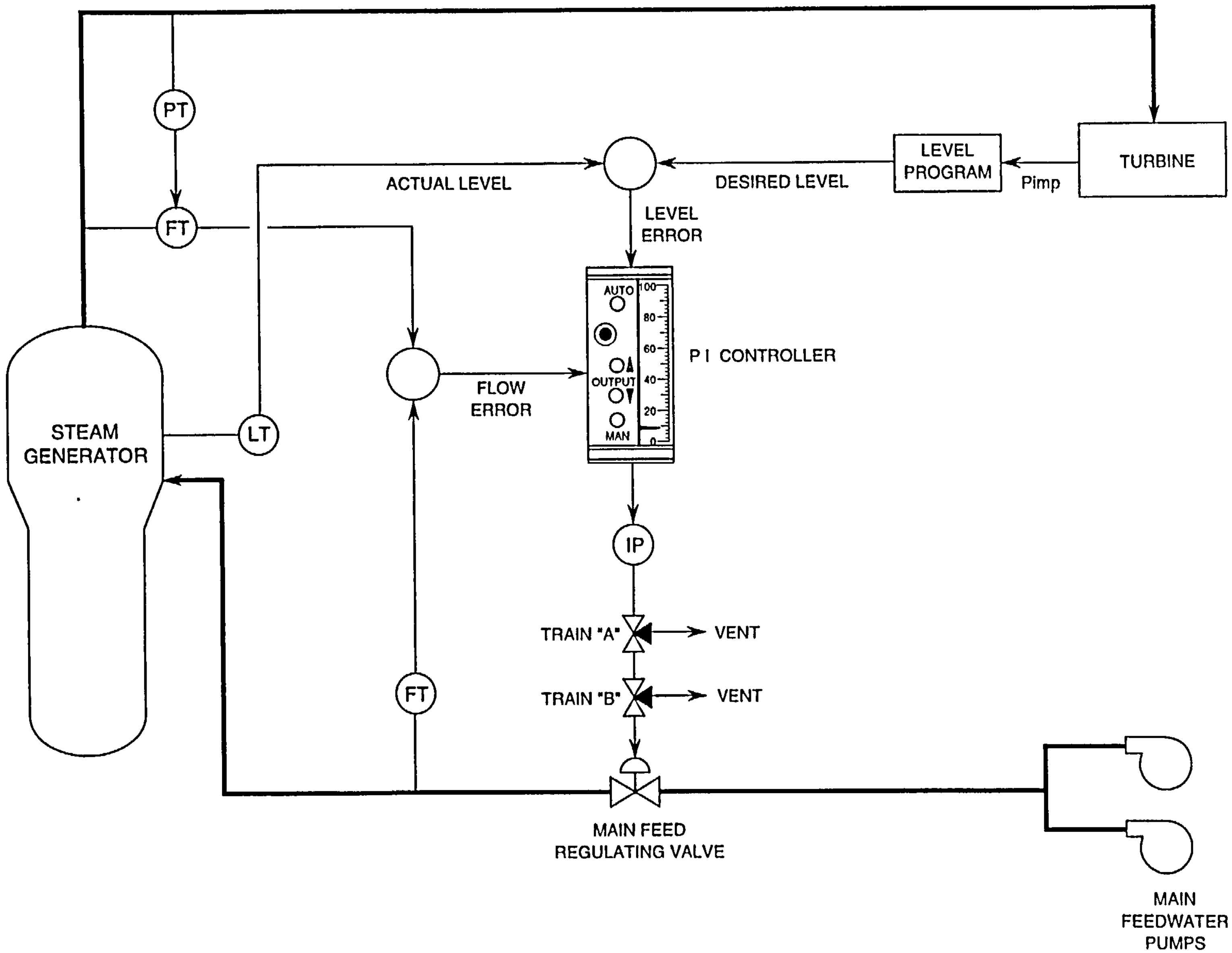

Figure 11.1-1 Steam Generator Water Level Control

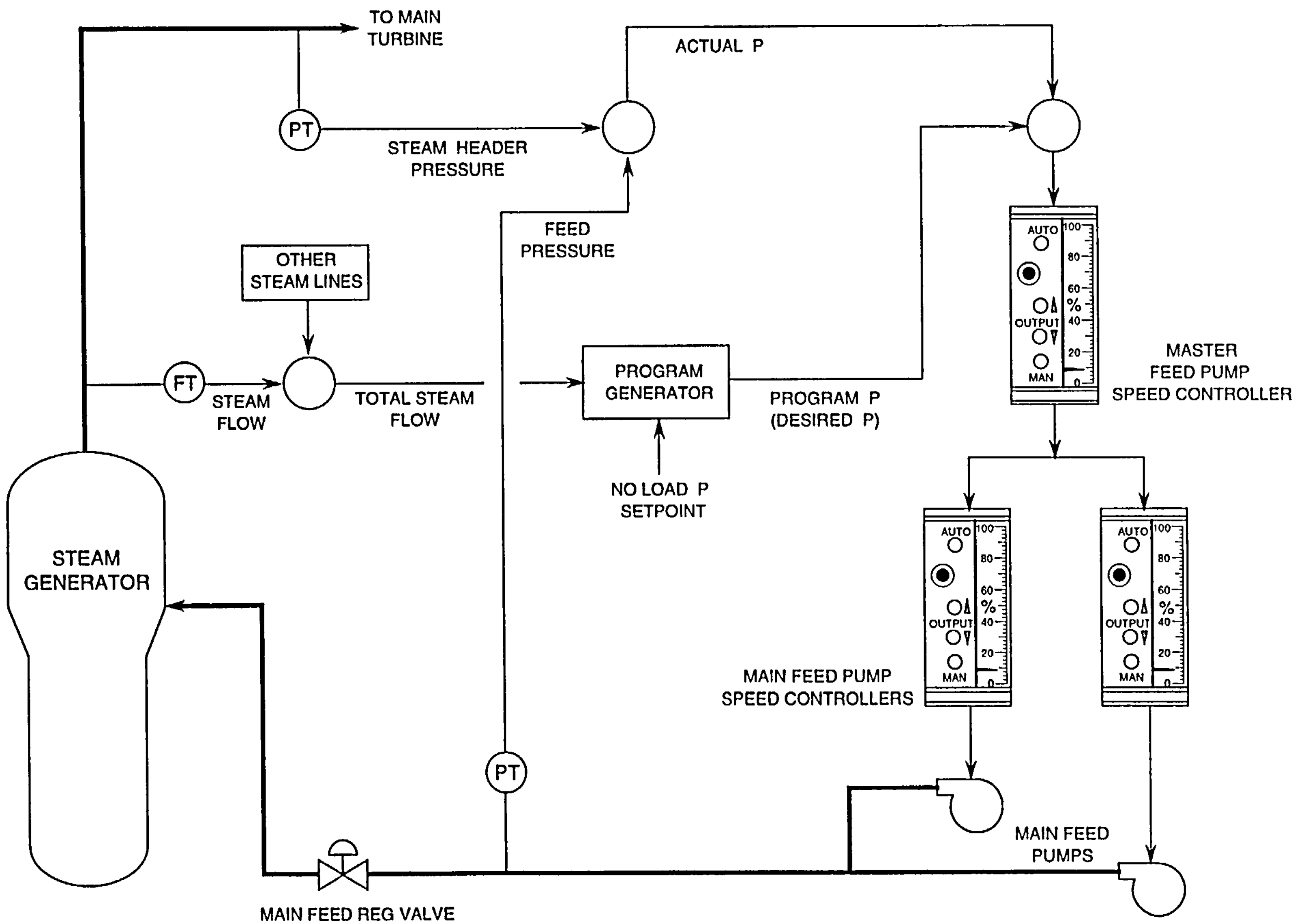

Figure 11.1-2 Feed Pump Speed Control

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Section 11.2

Steam Dump Control System

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11.2 STEAM DUMP CONTROL SYSTEM

Learning Objectives:

1. List the purposes of the steam dump system.

2. Briefly explain how each purpose is accomplished.

3. Describe how the system functions in:

   a. Steam pressure mode, and
   b. T_{avg} mode.

4. List the input signals to the steam dump control system.

5. List the "arming" and "interlocking" signals.

11.2.1 Introduction

The steam dump system is provided to accommodate the inertial heat from the primary cycle. Inertial heat, in the form of steam generated in excess of turbine demand, is present at times of sudden load reduction since the nuclear power cannot be instantly reduced. This heat is rejected to the condenser through the steam dump valves or to the atmosphere through the steam line safety and relief valves for the initial phase of large load reductions.

The dump valves are also utilized in pressure control mode during plant startup and plant cooldown. Prior to synchronizing the generator to the grid, reactor power may be increased up to 10 percent by dumping steam to the condenser. This will facilitate establishing the minimum turbine-generator load (5 - 10%) without placing a step-load demand on the reactor system. The dump valves close automatically as steam is admitted to the turbine. During plant cooldown, steam is dumped to the condensers to provide a heat sink rather than to atmosphere through the atmosphereic dump valves. This conserves condensate in the system.

The control system for the steam dump is shown on Figure 11.2-1. The steam dump system and its control system are considered control grade systems that are not required for a safe shutdown of the reactor.

11.2.2 System Description

The twelve steam dump valves are divided into four groups of three valves (Figure 11.2-1). The valves are air operated and sequentially opened in groups as the control signal increases. The first group is modulated fully open before the second group begins to open. Each valve has a positioner which regulates air pressure to the valve operator based on an instrument air signal from a group positioner. The four group positioners get an air signal from from the current to pressure (I/P) converter, which gets its input from one of three controllers (Figure 11.2-2). The steam dump control system operates in two modes; Tavg mode and steam pressure mode. The mode of control and plant conditions will determine which controller is used. Each controller has a different pair of input parameters.

Interlocks and arming signals will prevent or halt operation of the steam dump when not needed or desired, or in the event of an instrument failure.

11.2.2.1 Interlocks

Interlocks prevent the steam dump valves from being opened if their functioning could cause either equipment damage or uncontrolled cooldown of the reactor coolant system. Figure 11.2-1 shows the interlock signals to a typical steam dump valve. All twelve dump valves have these interlocks.

The "condenser available" interlock prevents opening steam dumps if the condenser does not have at least one circulating water pump running or if the condenser vacuum is not adequate. Blowing steam into the condenser could severely damage the condenser if either adequate cooling water or condenser vacuum is unavailable.

The "condenser available" interlock functions by opening a contact in the DC power supply to two solenoid-operated valves in the air supply line to the steam dump valves. If these solenoid valves are deenergized, they position to shut off the air supply to the steam dump valves. The dump valves are spring loaded to close.

The Low-Low T_{avg} (< 540°F) interlock prevents the steam dump valves from opening if temperature in the reactor coolant system drops below 540°F. This prevents inadvertent cooldown of the reactor coolant system (and the reactivity associated with that cooldown). This interlock may be bypassed by the operator, which allows the use of a single group of three dump valves for a controlled cooldown of the reactor coolant system.

11.2.2.2 Arming Signals

If all of the interlocks described above are satisfied, the steam dumps will respond only if an "arming" signal is present (Figure 11.2-1). By using "arming" signals, steam dump operation is blocked until its operation is required. The "arming" signals are:

1. "Mode Selector Switch" placed in the "Steam Pressure" mode of control. This position allows the system to control steam header pressure (and thereby reactor coolant system temperature) to an operator-selected reference pressure (Figure 11.2-3). By adjusting the reference pressure, the operator can make the steam dump valves open or close to change T_{avg}. This is the mode used during plant cooldowns.

2. A turbine load rejection greater than the design capacity of the automatic rod contorl system (5%/minute or 10% step change). This condition is beyond the control rod capability. The steam dumps will arm and open to dissipate the inertial heat of the reactor coolant system. A load rejection is determined by monitoring the change in turbine impulse pressure.

3. Reactor trip. Since tripping the reactor also trips the turbine, steam dumps will actuate to bring the reactor coolant system T_{avg} back to the no-load value of 547°F.

Arming signals block steam dump operation until required, reducing the chance of unnecessary or unwanted actuation.

11.2.2.3 Control Signals

In addition to requiring all interlocks and at least one of the three arming signals present, a control signal must also be present in order for the steam dumps to operate. It is the control signal that actually provides the motive force (compressed air) to open the steam dump valves (Figure 11.2-2). The source of the control signal is dependent on the mode of operation as determined by the "mode selector" switch. The signal is genrated by one of the three controllers:

1. Steam Pressure Mode Controller
   Produces an output when steam header pressure is greater than the operator-selected setpoint pressure.

2. T_{avg} Loss-of-Load Controller
   Produces an output when auctioneered high Tavg is 5°F or more above T_{ref}.

3. T_{avg} Reactor Trip Controller
   Produces an ouput when auctioneered high T_{avg} is greater than the no-laod setpoint of 547°F.

These controllers and their operations are explained under "Steam Dump Operations."

11.2.3 Steam Dump Operations

When one of the three controllers produces an output, it is indicative of an "error" signal. The error is either a pressure error (steam pressure mode controller) or a temperature error (T_{avg} mode controllers). The magnitude of the error is proportional to the current of the controller's output. This current signal is converted to a variable pressure control air signal in the I/P converter. The control air signal operates individual valve positioners for each of the twelve dump valves. Grouping and modualtion setpoint of individual valves is controlled by the setpoint adjustment of the positioners. In the valve positioner, the control air signal controls the admission of 100 psig instrument air to operate the steam dump valve. Actual pressure of the instrument air is variable and dependent on the pressure of the control air. Pressure of the instrument air regulates the opening of the steam dump valves.

The operating air can reach the diaphragm of the dump valve only if both arming and interlock signals are available. If all interlocks are met and an arming signal is present, the solenoid valves will align operating air to the steam dump valve diaphragm. If any of these conditions are not met, the solenoid valve will align to vent operating air to atmosphere. Two series solenoid valves are in the operating air line to each steam dump valve.

11.2.3.1 Steam Pressure Mode of Control

This mode of control is "armed" whenever the Mode Selector Switch (Figure 11.2-3) is in the Steam Pressure position. The error signal to operate the dumps is generated by the difference between actual steam header pressure and a manually chosen setpoint pressure. The error signal operates dump valves as described in Section 11.2.3 above. Steam pressure control is utilized during plant startup and plant cooldown operation.

During plant startup, the pressure setpoint chosen is no-load steam pressure (1005 psig). As the plant is heated, utilizing reactor decay heat and coolant pump heat, the steam dump will open when steam pressure exceeds no-load. This will halt further heatup by dissipating excess decay and pump heat to the condenser, thus maintaining the plant at the hot, no-load condition. As the reactor is made critical and power increased to the heating range, reactor temperature will increase. This will cause steam temperature and pressure to increase; however, the steam dump will receive a larger error signal and open to dissipate the excess reactor power to the condenser. By providing this "artificial load," reactor and steam generator level control during plant startup is simplified.

During plant cooldown, the steam pressure controller signal is manually adjusted to dissipate more energy to the condenser than the combination of pump heat and decay heat input. This will result in a cooldown of the reactor coolant system. This method is continued until the residual heat removal system can be aligned to continue cooldown. An interlock bypass system is provided to allow limited dump operation at less than 540°F during cooldown.

11.2.3.2 T_{avg} Control

T_{avg} is the normal, at power, operating mode for the steam dump control system. In this mode (Figure 11.2-4), the steam dump will respond to control error signals during either load rejection or reactor trip conditions. Each of these conditions has its own controller and operational characteristics.

11.2.3.2.1 T_{avg} Control Mode - Load Rejection

On a load rejection of greater than 5% ramp or 10% step, the control rods will be inserted (as turbine power is less than reactor power). If the load rejection is greater than the capacity of the rod control system, T_{avg} will increase. If the T_{avg} - T_{ref} error exceeds 5°F, the steam dump valves will begin modulating to provide an artificial load and minimize the T_{avg} increase. Selecting a "deadband" of 5°F error before the steam dump operates allows the rods to control the transient if possible.

As the control rods continue to insert, lowering reactor power, the steam dump error signal will decrease, and the steam dump valves will ramp shut. The steam dump valves ramp open and shut in groups of three with the first group receiving a full open signal before the second group begins to open. After the transient is complete and steam dump valves are shut, the "seal-in" arming signal must be reset. This is accomplished by momentarily selecting "Reset" on the "Mode Selector" switch. This returns the load rejection sensor to normal and enables it to sense any future load rejection.

11.2.3.2.2 T_{avg} Control Mode - Reactor Trip

This mode of control is used in the event of a reactor trip. The reactor trip controller works essentially the same as the load rejection controller except that the error signal is generated by the mismatch between T_{avg} and no-load T_{avg} (547°F). This control is "armed" when a reactor trip occurs and the "Mode Selector" switch is in the T_{avg} position. An error signal is generated starting from a zero mismatch and increases 100% linearly as the mismatch increases. It is not necessary to delay the opening of the steam dumps to allow control rod operation, because the trip has dropped the rods into the core and also tripped the turbine. The remaining components operate the same as during load rejection control.

If the reactor and the turbine trip, the steam dumps must open to dissipate core decay heat and lower T_{avg} from its program setpoint to the no-load setpoint.

11.2.4 Summary

The steam dump system provides an alternate load for the primary system on a load reduction to prevent a reactor trip; to return the plant to no-load conditions following a reactor trip; and to maintain plant conditions during startup and cooldown. Arming signals and interlocks prevent inadvertent operation in the event of instrument or system failure. The steam dumps are not required for the safe shutdown of the reactor.

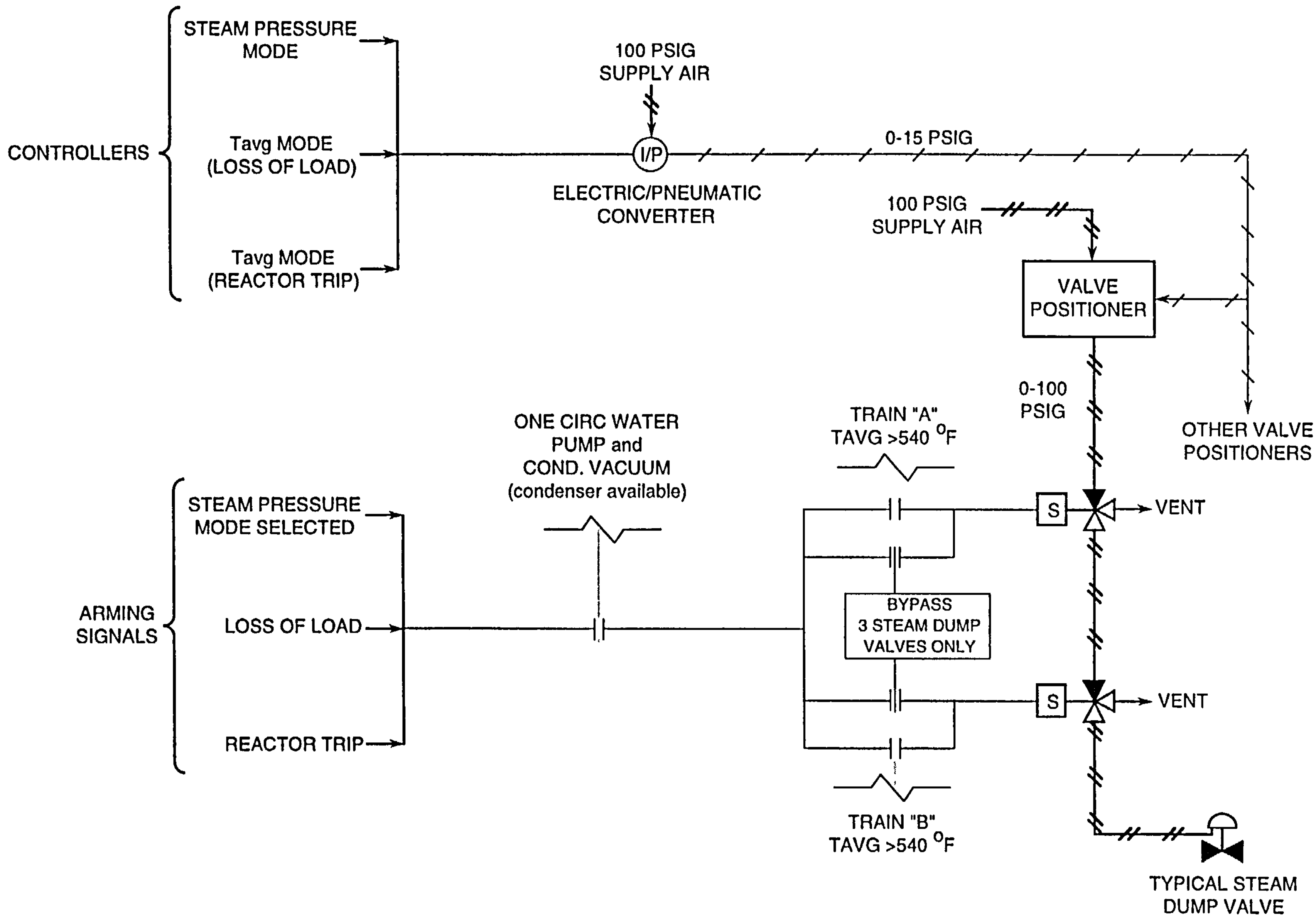

Figure 11.2-1 Steam Dump Control (Simplified)

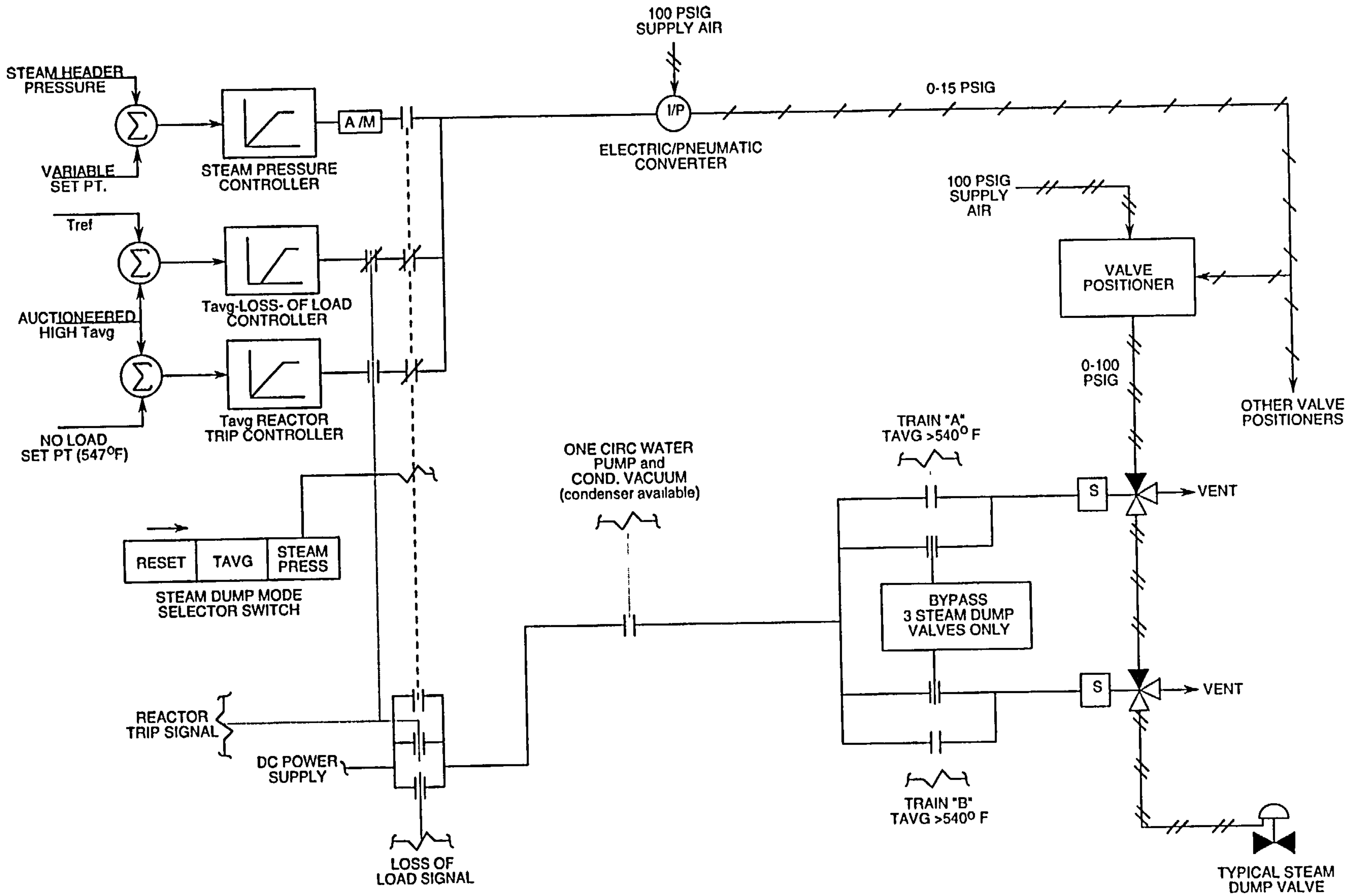

Figure 11.2-2 Steam Dump Control System

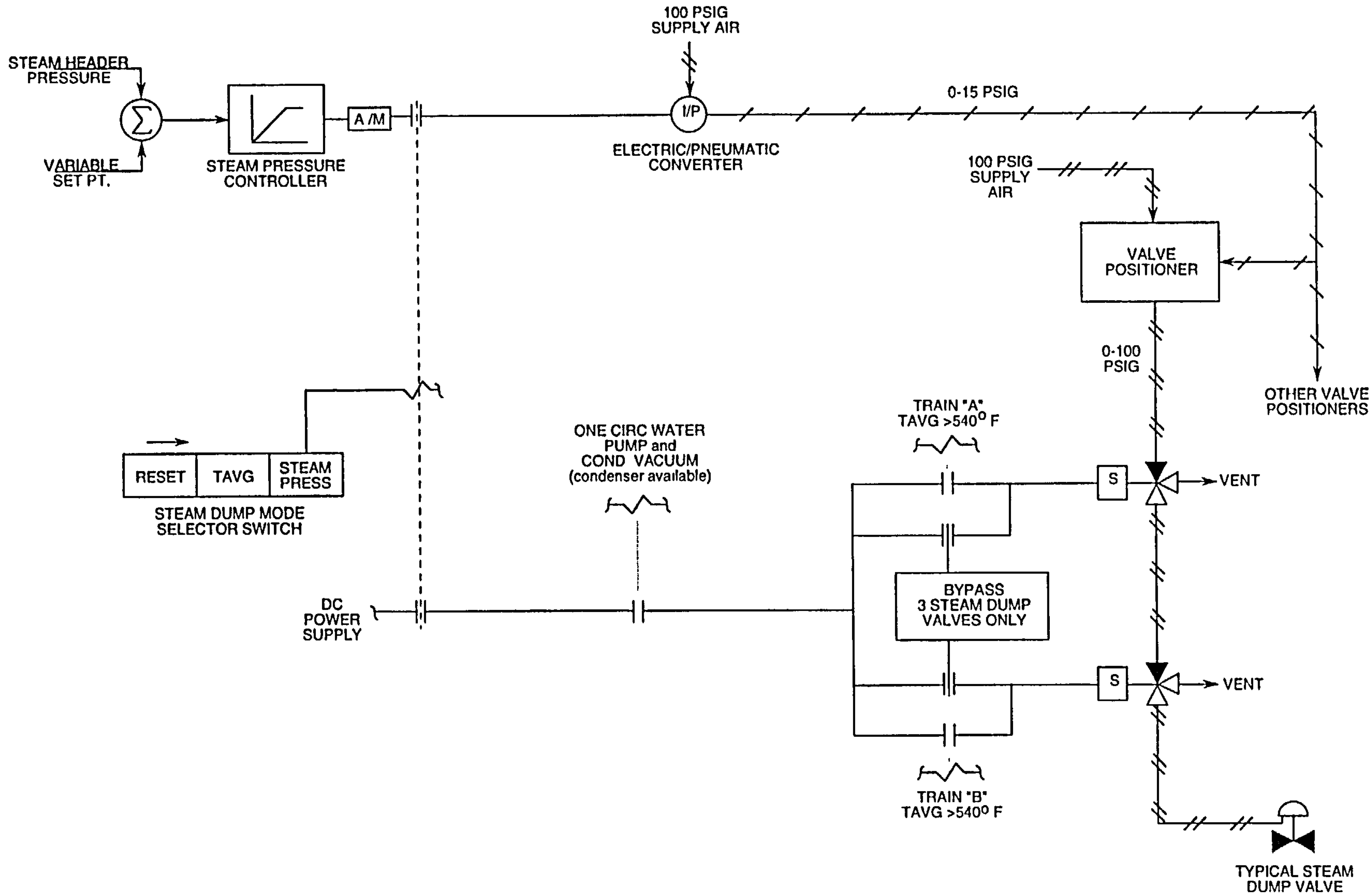

Figure 11.2-3 Steam Pressure Control Mode

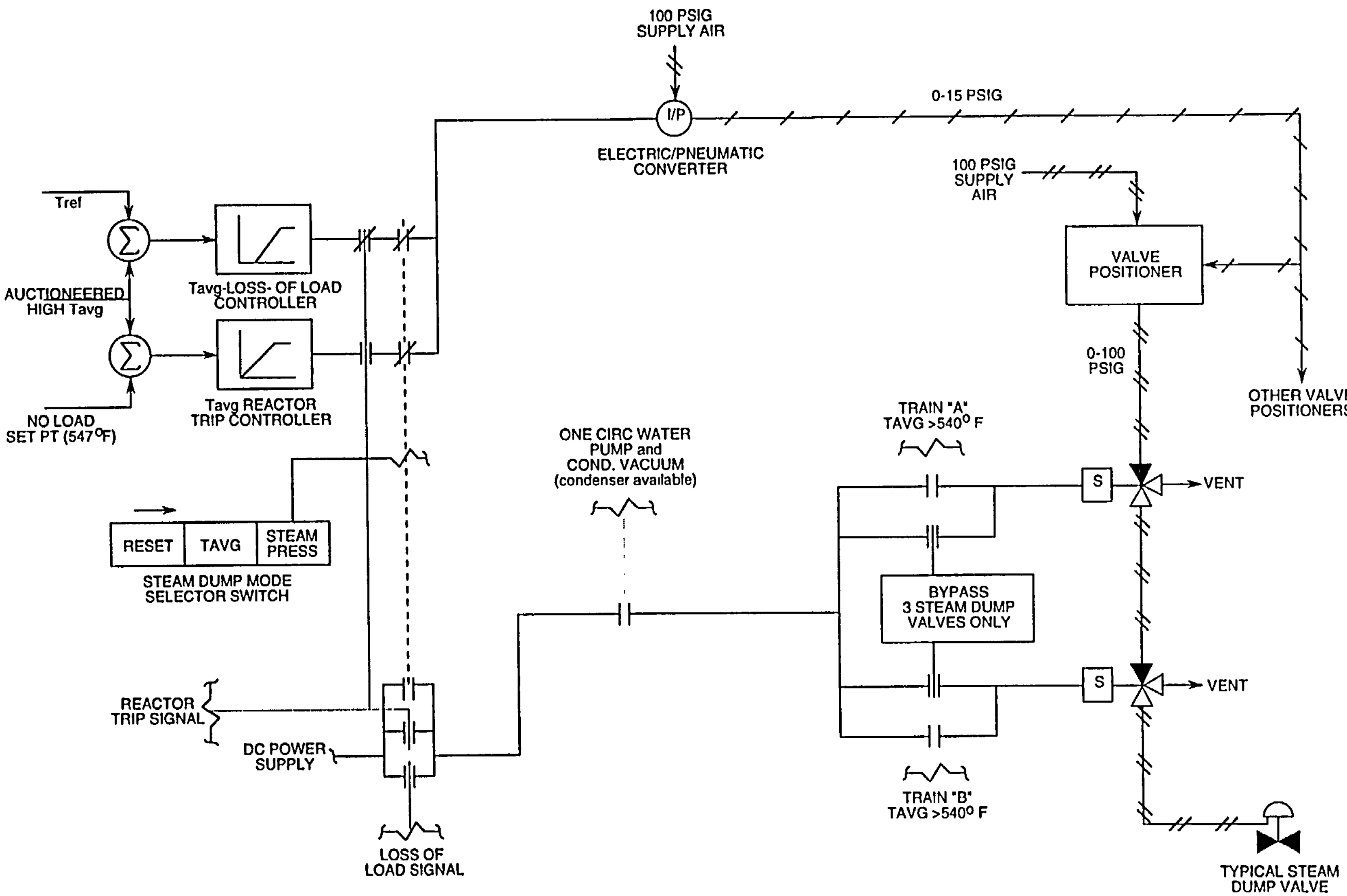

Figure 11.2-4 Tavg Control Mode

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Chapter 12.0

Reactor Protection System

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12.0 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the purpose of the reactor protection system.

2. Describe how the purpose of the reactor protection system is accomplished.

3. Explain and give an example of how each of the following is incorporated into the design of the reactor protection system:

   a. Redundancy,
   b. Independence,
   c. Diversity,
   d. Fail safe,
   e. Testability, and
   f. Single failure criteria.

4. Given a list of reactor trips, explain the purpose of each.

5. State the purpose of the engineered safety features actuation system.

6. Describe how the purpose of the engineered safety features actuation system is accomplished.

7. List each of the five engineered safety feature actuation signals and the specific accident each is designed to handle.

8. List the systems or equipment which are actuated or tripped upon the receipt of an engineered safety features actuation signal.

12.1 Introduction

The purpose of the reactor protection system (RPS) is to prevent the release of radioactivity to the environment. To meet this objective, the RPS will act to prevent unsafe operation of the reactor which could lead to accident conditions. The prevention of unsafe operation is accomplished by the initiation of a reactor trip by the RPS. If an accident does occur, the RPS will actuate engineered safety features (ESF) which are designed to mitigate the consequences of an accident.

The dictated safe operating limits bounded by reactor trips and ESF actuation are monitored by sensors to detect the necessary parameters. These parameters are measured by analog circuitry for trip setpoint comparison and compared in digital logic circuitry to initiate reactor trips or ESF actuation. Trip actuation is based on the number of analog signals that have exceeded their respective setpoints. These four basic functions (monitoring, measuring, comparing, and initiating) are performed by the RPS.

12.2 Reactor Protection System Design

A reliable system of reactor protection is needed to guarantee the integrity of the reactor systems and avoid undue risk to the health and safety of the public. The system must be capable of supplying reactor and component trip signals and initiating ESF to provide the required degree of protection for all normal operating and casualty conditions. A simplified diagram of the reactor protection scheme is shown in Figure 12-1. The nuclear and process instrument systems send trip signals to the logic trains. The two trains are complete and independent sets of logic circuits in the RPS cabinets. When an unsafe condition is sensed, a signal is sent to the protection cabinets. If a reactor trip is required, the protection cabinets will send a signal to the reactor trip breakers. Tripping of these breakers will remove power from the control rod drive mechanisms allowing the rods to drop into the reactor core. If a safety features actuation is required, the protection cabinets will actuate the appropriate engineered safety features devices. Permissive signals are also provided by the logic trains to allow automatic or manually initiated interlocks and bypasses.

12.2.1 Design Features

The high degree of reliability required of the RPS is attained by the incorporation of the following features:

a. Redundancy:
Maintaining at least 100% backup ensures redundancy. The two in-series reactor trip breakers is an example. Either breaker performing its intended function (opening on a reactor trip signal) will provide full protection.

b. Independence:
Physical as well as electrical separation of sensors, power supplies, and equipment helps ensure independence. The object is to prevent any failure or accident from rendering more than one redundant sensor, channel, or device inoperable.

c. Diversity:
Providing more than one way of performing a function or of monitoring a parameter is an example of diversity. Since reactor coolant system flow is important to safe operation, diverse methods of detecting low flow conditions are used. Elbow flow taps and/or pump breaker open position indicators can cause a reactor trip on low flow.

d. Fail Safe:
The most likely failure of this or any electrical system would be a loss of input power. If power is lost to a channel, it fails to the tripped condition. If power is lost to the logic train, a reactor trip will result.

e. Testability:
On line testing of the reactor protection system is provided to assure that this system will perform its functions as designed. Calibration and testing of the various portions of the reactor protection system, such as individual channel detectors, bistable trip setpoints or the logic racks, can be performed without preventing or causing a protective function.

f. Single Failure Criteria:
The single failure or loss of a protection channel or component will not prevent the reactor protection system from performing its design function. This includes all systems and components that are actuated if the reactor protection system generates an engineered safety features actuation.

The protection system is designed to be independent of the control systems. In certain applications, the control signals and other non-protective functions are derived from individual protective channels through isolation amplifiers. The isolation amplifiers are classified as part of the reactor protection system. Non-protective functions include those signals used for control, remote process indication, and computer monitoring. The isolation amplifiers are designed such that a short circuit, open circuit, or the application of either AC or DC voltage on the isolated output portion of the circuit (i.e., the non-protective side of the circuit) will not affect the input (protective) side of the circuit.

The signals obtained through the isolation amplifiers are never returned to the protective racks.

Where failure of a protection system component can cause a process excursion which requires protective action, the protective system can withstand another independent failure without loss of protective action.

12.3 System Description

A simplified diagram of the reactor protection system is shown on Figure 12-2.

This diagram is shown with only one of the protective features, using signal transmitters associated with four channels such as pressurizer pressure. These pressure transmitters will provide an analog (variable) signal to the analog cabinets. The analog cabinet, with the use of bistables, will compare the analog signal with a preselected setpoint. If the analog signal is equal to or exceeds the setpoint (sensing an unsafe condition), the bistable will trip (turn off). A bistable is essentially an electronic switch that is either on or off. Note that a loss of power for the bistable turns its output off. It "fails safe" on loss of power.

The logic section of the reactor protection system is divided into two independent, separate, and redundant trains (Train "A" and Train "B"). Each receives a digital (on or off) signal from the analog cabinets' bistables. The logic section is that portion of the reactor protection system where the coincidence for a particular trip is determined. If an unsafe condition of operation occurs such as pressurizer pressure low, on two out of four (2/4) instruments, then a reactor trip signal is transmitted from the logic sections to the undervoltage coils of the reactor trip breakers.

De-energizing the undervoltage coil on the series reactor trip breakers causes the breakers to trip (open). Opening either of these breakers removes all power from the control rod drive power cabinets, which in turn de-energizes all the magnetic coils on the rod drive mechanisms, allowing the rods to fall into the reactor core. If an engineered safety features actuation is required, the logic sections will actuate (open, close, start, or stop) the appropriate safety equipment.

Permissive signals are also provided by the logic sections. Permissive signals allow for automatic or manual (with the use of control board switches) bypassing or blocking of certain reactor trips and engineered safety features signals when they are not required. The reactor protection system is designed so that if a particular trip is bypassed and plant conditions change where this trip may be required to ensure plant safety, the trip will be automatically unblocked.

12.3.1 Reactor Trip Descriptions

The core protection system philosophy is to define a region of permissible operation in terms of power, flow, axial power distribution, and primary coolant temperature and pressure so that the reactor is tripped when the limits of this region are approached.

The remainder of this section will provide a brief description of the reactor trip signals generated by the reactor protection system. A full list of the reactor trip signals, which contains the coincidence of the trips, setpoints, interlocks, etc., is given in Table 12-1.

The various permissive and interlock signals are listed in Table 12-3. Control grade (non-protective) interlocks are listed in Table 12-4.

a. Overtemperature ΔT (OTΔT) Trip (Figure 12-3)

The purpose of this trip is to protect the core against departure from nucleate boiling and subsequent cladding failure. There are four OTΔT channels requiring a 2/4 logic to trip. The continuously variable trip setpoint is calculated for each channel by solving the following equation:

$$\Delta T_{setpoint} = \Delta T_{rated}[K_1 - K_2(T_{avg} - T_{avg\ rated}) + K_3(P - P_{rated}) - f(\Delta I)]$$

where:

T_{avg} = Reactor coolant average temperature
P = Pressurizer pressure
$f(\Delta I)$ = A signal generated by the flux difference between the top and bottom of the core (axial power distribution)
K_1, K_2, K_3 = Constants defined for 3 and 4 loop operation

The setpoint calculator for each channel receives separate and redundant pressure, temperature, and flux signals.

By the equation, an increase in T_{avg} will cause the setpoint to decrease; a decrease in pressure will cause the setpoint to decrease; and a worsening axial flux distribution will cause a setpoint decrease. Each of these parameter changes causes a decrease in the departure from nucleate boiling ratio and therefore requires a more conservative trip setpoint. If the actual ΔT equals the calculated ΔT setpoints minus 3%, an automatic turbine runback and rod withdrawal block will occur to attempt to stop the transient before reaching the trip setpoint.

b. Overpower ΔT (OPΔT) Trip (Figure 12-4)

This trip protects against excessive linear heat generation rates (Kw/ft) which could cause high fuel centerline temperature with resultant fuel element cladding damage. There are four OPΔT channels requiring a 2/4 logic to trip. The continuously variable trip setpoint is calculated for each channel by solving the following equation:

$$\Delta T_{setpoint} = \Delta T_{rated}[K_4 - K_5 d/dt T_{avg} - K_6(T_{avg} - T_{avg\ rated}) - f(\Delta I)]$$

where:

T_{avg} = Reactor coolant average temperature
$d/dt T_{avg}$ = Rate of change of T_{avg} (increase only)
$f(\Delta I)$ = A signal generated by the flux difference between the top and bottom of the core (axial power distribution)
K_4, K_5, K_6 = Constants defined for 3 and 4 loop operation

An increase in the rate of change of T_{avg} or and increase of T_{avg} above $T_{avg\ rated}$ (indicating high reactor power) will cause a decrease in the ΔT rated setpoint. A turbine runback and rod block are provided as in the previously described overtemperature ΔT trip circuit.

c. High Neutron Flux (power Range) Trip

This trip occurs if 2/4 power range channels exceed their setpoints. There are two independent trip setpoints, a high and a low setting.

(1) High setpoint - Overpower protection. This trip and the OTΔT and OPΔT are the primary protection for the reactor. The high setpoint nuclear power trip protects against transients too rapid for OTΔT and OPΔT. A rod withdrawal block is provided to prevent reaching the trip setpoint due to rod control system malfunction or operator error. Trip setpoint is 109%, rod block at 103%.

(2) Low setpoint - Provided as startup protection and set at approximately 25% power. This may be manually blocked when nuclear power exceeds 10% (P-10) during a plant startup.

d. Positive Neutron Flux Rate

This circuit trips the reactor when an abnormally high positive rate of change of nuclear power is sensed by 2/4 power range channels. Protects against possible ejected control rod.

e. Negative Neutron Flux Rate

This circuit trips the reactor when an abnormally high negative rate of nuclear power change is sensed by 2/4 power range channels. Protects against high flux peaking resulting from one or more dropped rods.

f. High Neutron Flux (Intermediate Range)

Provided as startup protection and may also be manually blocked when nuclear power exceeds 10% (P-10) during a reactor startup. Trip logic is 1/2 channels above the trip setpoint. A rod withdrawal block is provided at a power slightly below the trip to prevent reaching the trip setpoint on a rod control malfunction or operator error.

g. High Neutron Flux (Source Range)

Provided as startup protection and may be manually blocked when intermediate range overlap is established as determined by permissive P-6.

NOTE: All nuclear instrumentation system trips which are manually blocked during a startup are automatically reinstated as the plant is shut down.

h. High Pressurizer Pressure

Reactor coolant system overpressure protection will trip the reactor trip if 2/4 pressurizer pressure channels exceed the trip setpoint.

i. Low-Low Steam Generator Level

Loss of heat sink protection will trip the reactor is 2/3 narrow range sensors <u>on any one</u> steam generator indicates a low-low level.

j. Low Feedwater Flow

Anticipatory loss of heat sink protection will trip the reactor if low feed flow and low level are sensed simultaneously on any one steam generator.

k. Engineered Safety Features Actuation Trip

A reactor trip is initiated whenever the engineered safety features are actuated. The signals which actuate the engineered safety features are discussed in Section 12.3.2.

l. Manual

The operator can manually trip the reactor if he/she determines it to be in an unsafe condition.

NOTE: The following three trips are automatically blocked at low power and automatically reinstated when nuclear or turbine power is above 10%. They are commonly known as the "at power" trips and are interlocked by permissive P-7. The logic for the permissive signals, P-7, P-10, and P-13 are shown on Figure 12-5.

m. Low Pressurizer Pressure

Limits the range over which the OTΔT trip is required to protect against DNB. Trips the reactor before excessive boiling and DNB occur (2/4 logic, rate compensated).

n. High Pressurizer Water Level

Provided as a backup to the pressurizer high pressure trip and to trip the reactor prior to discharging water through the safety valves (2/3 logic).

o. Coolant Flow Trip Signals

Protect the core from DNB following a loss of coolant flow.

(1) Low Reactor Coolant Flow
A loop low flow signal generated by 2/3 flow sensors per loop. Above P-7 (10%), low flow in two loops will result in a reactor trip; above P-8 (approximately 35% nuclear power), low flow in a single loop results in a reactor trip.

(2) Reactor Coolant Pump Breaker Open
Logic similar to (1) above. Anticipates low flow due to reactor coolant pumps deenergizing.

(3) Undervoltage on Reactor Coolant Pump Bus
Anticipated low flow in loop. Trips reactor if 2/4 reactor coolant pump busses indicated less than 75% of normal.

(4) Underfrequency on Reactor Coolant Pump Bus
Anticipates low flow in loop. Trips reactor if 2/4 reactor coolant pump busses indicated frequency of 57 Hertz or less.

p. Turbine Trip

Above P-9 (50%), a turbine trip yields a direct reactor trip to limit the resultant thermal transient in the reactor coolant system. Protection could also be provided by the overtemperature ΔT and high pressure trips. However, these trips would only terminate the transient. The reactor trip from turbine trip prevents the excursion which would result in the overtemperature and overpressure condition.

12.3.2 Engineered Safety Features Actuation

The engineered safety features are provided to limit the effects of and limit the offsite dose due to a reactor coolant system pipe rupture or steam break accident. An initial injection of concentrated boric acid counteracts the positive reactivity effect associated with the cooldown resulting from a steam break. This initial volume is followed by a larger volume of boric acid solution to ensure continuous core coverage and heat removal. Any engineered safety features signal (sometimes labeled SI for safety injection) will initiate actions to place the plant in a stable, safe shutdown condition (Figure 12-6). Regardless of the accident or condition initiating engineered safety features actuation, the following events are implemented by the reactor protection system:

1. Reactor trip.

2. Safety Injection Sequence - The high head injection portion of the chemical and volume control system is aligned to the reactor coolant system cold legs, the high head centrifugal charging pumps are started, and the residual heat removal pumps and the safety injection pumps are started (residual heat removal and safety injection systems will already be aligned to inject from the refueling water storage tank into the cold legs). Refer to Section 5.1 for a detailed description.

3. Phase "A" Containment Isolation - Dual isolation valves in all non-essential containment penetration lines are shut. The only exceptions to this isolation of non-essential lines are the component cooling water supply and return lines for the reactor coolant pumps and the main steam line isolation valves. The reactor coolant pumps, although not essential, can be used to circulate coolant through the core. The main steam line isolation valves can be kept open because they are part of a high pressure, closed cycle system. While they are open, the steam dump system may be used to remove core heat. The main steam line isolation valves will go closed if the initiating signal is the high steam line flow engineered safety feature. This is done to keep all four steam generators from blowing down on the (assumed) downstream steamline break.

4. Auxiliary Feedwater Initiation - The auxiliary feedwater system provides a reliable, safety grade source of water to the steam generators to ensure a heat sink is available.

5. Main Feedwater Isolation - Main feed is isolated to limit an inadvertent cooldown if an unisolable steam break occurs.

6. Emergency Diesel Generator Startup - The diesel generators are the power source for emergency system on-site if off-site power should be lost. They are started "just in case" the off-site power is unavailable. The diesels will run in standby and will not supply the engineered safety feature loads until required by a loss of off-site power.

7. Auxiliary Cooling System Line-up - The service water system and the component cooling water system will align to their engineered safety features modes, and the correct number of pumps in each system will automatically start. Refer to Chapter 5.4.

8. Control Room Intake Duct Isolation - The ventilation supply to the control room will

realign to a self-contained habitability system to prevent smoke or radiation levels in the auxiliary building from causing control room evacuation.

9. Containment Ventilation Isolation - The containment purge and exhaust system is periodically used to ventilate containment atmosphere prior to personnel entry. These systems will be isolated in case they are running when an accident occurs.

12.3.3 Resetting Engineered Safety Features Initiation

Once an engineered safety features actuation has been initiated, whether from an accident or inadvertently, manually or automatically, a retentive memory device is placed in the "ON" position (Figure 12-6). This means that the nine engineered safety features functions described above will continue to receive their initiation signal even if the original engineered safety features initiation signal is removed or cleared. Additionally, the operator cannot interrupt any of the engineered safety features functions until a time delay (usually one minute) has occurred. This "locking out" of the operator is important to insure against inadvertent interruption of a valid engineered safety features initiation. Additionally, some of the engineered safety features functions take several seconds to complete their alignment. Interrupting the initiating sequence could leave some systems in bewildering arrangements. In addition to the time delay, a reactor trip must also be in effect before the engineered safety features signal can be blocked by the operator.

Once the block permissive (time delay relay timed out and a reactor trip in effect) is made, the operator can manually block the engineered safety features initiation signal and place the retentive memory device in the "OFF" position. This action does not turn any of the engineered safety features equipment off, realign valves or change any of the engineered safety features functions. It does, however, restore the operator's ability to rearrange equipment lineups and start or stop equipment as needed to control the plant. The one minute time delay gives the operator time to assess the situation and determine a course of action up to and including the realignment for the recirculation phase of safety injection in the event of a large loss of coolant accident.

12.3.4 Engineered Safety Features Equipment

The engineered safety features are initiated when the reactor protection system sensory and logic network detect the occurrence of either a loss of coolant accident or a steam line break. Both of these accidents require certain safety features to be employed to ensure the safety of the public and the reactor core. Whatever the nature of the accident, the functions of the engineered safety features are to (Figure 12-6):

(1) Put the plant in a safe shutdown configuration (including both a reactor trip and boron injection).

(2) Provide cool borated water at a rate sufficient to prevent gross core damage from a loss of coolant accident.

(3) Isolate containment from the outside environment to limit radioactive effluent releases.

(4) Provide a heat sink in the form of auxiliary feedwater so the residual heat of the core can be removed.

(5) Provide a source of reliable emergency power (diesel generators) in case off-site power is unavailable.

12.3.5 Engineered Safety Features Actuation Signals

There are five engineered safety features actuation signals, four automatic plus manual. Each is discussed below. Refer to Table 12-2 for setpoints and coincidence of each.

1. Low Pressurizer Pressure
   Designed specifically to be indicative of a loss of coolant accident. May be manually blocked by the operator to allow normal cooldown and depressurization. Permissive interlock is P-11.

2. High Containment Pressure
   Designed to serve as a backup to the loss of coolant accident protection (low pressurizer pressure) and the upstream steam break protection (high steam line differential pressure). This is conceivable if the size of the assumed break is large enough to cause an increase in containment pressure but too small to trigger the initiation of the signal associated with that accident. Setpoint is usually 10% of design pressure of the containment.

3. High Steam Line Flow Rate Coincident with Either Low Steam Line Pressure of Low-Low T_{avg}
   This set of circumstances would occur if a steam line break occurs downstream of the isolation and check valves. A break in this area would essentially be common to all steam lines. It would also tend to drop steam pressures and reduce reactor coolant system temperature (Tavg). This signal may also be manually blocked to allow normal shutdown and cooldown. Permissive interlock is P-12. (Note: This actuation signal will also shut all four steam line isolation valves.)

4. Steam Line High Differential Pressure
   Indicative of a steam line break upstream of the steam line isolation and check valves. A break in this area would result in the affected steam line pressure dropping to a level significantly lower than the other lines due to the check valve seating in the affected line.

5. Manual
   Allows the operator to initiate engineered safety features from either of two board locations.

12.4 Summary

The reactor protection system serves as the principal information gathering and decision-making system to ensure the plant is being operated safely. The reactor protection system will initiate action to trip the reactor if unsafe conditions are approached and place the reactor in a safe, shutdown configuration. The reactor protection system also acts to limit the severity and consequences of all postulated accidents by initiation of engineered safety features.

The reactor protection system is designed, constructed, and tested to the highest standards commensurate with its importance to safety. This includes the requirement to meet single failures and still provide full protection, independence of the separate trains, and testability to ensure continued reliability.

A wide spectrum of reactor trips are used to prevent operations under unsafe conditions. Many of these trips are redundant to provide a high degree of diversity. Several permissive signals are provided to allow greater flexibility in plant operations. Interlocks are used to prevent an action or function from being performed under certain situations.

Engineered safety features are initiated to place the plant in the most stable, shutdown condition possible under certain accident situations. Engineered safety features reset interlocks prevent interruption of the safety features by the operators until completion of the sequence. After a brief time, the operator can regain control by manually resetting the engineered safety features initiation.

The Westinghouse reactor protection system consists of the process sensors (multiple sensors for each parameter) which produce a variable output to a comparator network (bistable). The variable signal from the sensor is compared to a pre-set bistable trip setpoint. If the process variable exceeds the setpoint, the bistable changes state and deenergizes its output. The bistable output is sent to both Train "A" and Train "B" logic cabinet. The logic cabinets continuously monitor the status of the bistables and will produce protective actions (trip or engineered safety features actuation) when the coincidence of tripped bistables indicate the need for protective actions. Either logic train is sufficient to provide full protective actions independent of the other logic train.

Table 12-1
SUMMARY OF REACTOR TRIPS

Trip	Co	Setpoint	Interlocks	Purpose	Accident
1 Source Range High Neutron Flux	1/2	10^5 cps	Manual block permitted by P-6, power to source range detectors is removed when manual block is initiated. Power to detectors cannot be turned on when power is above P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
2. Intermediate Range High Neutron Flux	1/2	Current equiva-lent to 25% power level	Manual block permitted by P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
3. Power Range High Neutron Flux - low setpoint	2/4	25%	Manual block permitted by P-10	Prevents an inadvertent power rise (excursion). A trip will occur unless the operator deliberately blocks the trip.	Reactivity addition accidents such as: a. Uncontrolled rod withdrawal from subcritical or low power condition. b. Inadvertent boron dilution. c. Excessive heat removal caused by steamline break or feedwater addition accidents.
4. Power Range High Flux - high setpoint	2/4	109%	No Interlocks	Limit maximum power level to prevent damage to fuel clad and protect against centerline melting	Inadvertent power excursions such as: a. Excessive load increase b. Excessive heat removal c. Boron dilution accidents d. Inadvertent rod withdrawal e. Rod ejection accident
5. High Positive Rate Neutron Flux	2/4	+5% change with a 2 sec. time constant	No Interlocks	Limit power excursions. Prevent unacceptable power distribution	Rod Ejection Accident

Table 12-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
6. High Negative Rate Neutron Flux	2/4	-3% change with a 2 sec time constant	No Interlocks	Prevent unacceptable power dist. Limit power overshoot from the rod control system which would withdraw rods to compensate for a dropped rod	Dropped Rod Accident
7. OTΔT	2/4	Variable, continuous calculation	No Interlocks	Prevent operation with DNBR <1.30	Relatively slow transients such as: a. Uncontrolled rod withdrawal at power b. Uncontrolled boron dilution c. Excessive load increase d. Depressurization of the RCS
8. OPΔT	2/4	Variable, continuous calculation	No Interlocks	Prevent excessive power density (KW/ft)	Relatively slow transients such as: a. Uncontrolled rod withdrawal at power b. Uncontrolled boron dilution c. Excessive load increase d. Steamline breaks
9. Pressurizer Low Pressure	2/4	1970 psig. (Rate compensated)	Disabled below P-7 (10%)	Prevent DNBR <1.30. Limit required range of OTΔT	Depressurization of RCS due to: a. LOCA b. Steamline break c. SG Tube Rupture
10. Pressurizer High Pressure	2/4	2385 psig.	No Interlocks	Protect integrity of RCS pressure boundary	Uncontrolled rod withdrawal at power, loss of electrical load, or turbine trip
11. Pressurizer High Water Level	2/3	92%	Disabled below P-7 (10%)	Prevent "solid water" operations, prevent discharge of high energy water through relief and safety valves.	Uncontrolled rod withdrawal at power, loss of electrical load, or turbine trip

Table 12-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
12. Low Reactor Coolant Flow	2/3	<90% Flow	P-8 (<39%) Loss of flow in one loop, no direct trip signal. P-7 (<10%) Loss of flow in two or more loops, no direct trip.	Ensure adequate loop flow to remove core heat. DNBR considerations.	Partial loss of RCS flow. Complete loss of forced RCS flow. Loss of off-site power to station auxiliaries.
13. Reactor Coolant Pump Undervoltage	1/1 on 2 bus- es	70% nominal bus voltage	Disabled below P-7 (10%)	Redundant to low flow trip	Redundant to low flow trip
14. Reactor Coolant Pump Under- frequency	1/1 on 2 bus- es	56 Hz	Disabled below P-7 (10%), trips open the pump motor breaker when actuated to preserve pump coastdown time	Redundant to low flow trip	Redundant to low flow trip
15. Steam Generator Low-Low Level	2/3 on 1/4	21% on narrow range	No Interlocks	Prevent Loss of heat sink	Loss of normal feedwater
16. Low SG Level in coincidence with steam flow/feed flow mismatch	1/2 lev- el and 1/2 flow on 1/4	25% SG level AND 40% mis- match $W_s > W_f$	No Interlocks	Anticipate loss of heat sink	Partial loss of normal feedwater
17. Turbine Trip	2/3 low auto oil. 4/4 T.S vlvs cls.	45 psig low auto stop oil pressure	Disabled below P-9 (50%)	Minimize primary system upset if turbine is tripped.	Turbine trip, loss of load
18. ESF Actuation			No Interlocks		Any accident requiring an Engineered Safety Features Actuation Signal

Table 12-1
SUMMARY OF REACTOR TRIPS

Trip	Co.	Setpoint	Interlocks	Purpose	Accident
19. Manual	1/2		No Interlocks	Operator initiated backup to all trips	Any condition requiring a reactor trip

Table 12-2
SUMMARY OF ENGINEERED SAFETY FEATURES ACTUATION SIGNALS

Signal	Coincidence	Setpoint	Interlocks	Accidents
Low Pressurizer Pressure	2/3	1870 psig.	Manual block. BLOCK switches enabled by P-11 (1920 psig).	Loss of coolant accident.
High Differential Pressure Between Steamlines	Any steamline 100 psi lower than any two of the remaining three steamlines.	100 psi ΔP.	No interlocks.	Steamline break upstream of the main steamline isolation valves.
High Steamline Flow COINCIDENCE WITH Low Steamline Press OR Low-Low T_{avg}	1/2 flow transmitters on two or more steamlines. 2/4 steamlines. 2/4 RCS loops.	Setpoint varies with turbine power. 600 psig. 540 °F.	Manual block. BLOCK switches enabled by P-12 (T_{avg} < 540°F) for a controlled plant shutdown and cooldown.	Steamline break downstream of the isolation valves (common to all steam generators). This signal also closes the main steamline isolation valves.
High Containment Pressure	2/3	2.9 psig.	No interlocks.	High energy break inside containment from LOCA, steamline, or feedline break.
Manual	1/2 Actuation switches on main control board		No interlocks.	Operator backup to any accident.

Table 12-3
SUMMARY OF PROTECTION GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Functions
P-4	Reactor Trip Breaker Contact	Open if trip breaker is closed. Closed if trip breaker is open	Trip breaker and its bypass breaker both open.	1. Trips main turbine 2. Trips main feed reg. valves with T_{avg} <554 °F on 2/4 channels. 3. Input to ESF block and reset logic. 4. If main feed regulating and bypass valves are tripped by SI or S/G high level, P-4 seals in the trip.
P-6	Source Range Block Permissive	Intermediate Range >10^{-10} amps.	1/2 Channels.	Enables the BLOCK/RESET switches to allow the operator to block SR high flux trip.
P-7	At-Power Permissive	Power < 10%.	Nuclear Power <10% (P-10) or, Turbine Power <10% (P-13).	Automatically blocks the "at-power" trips: 1. Pressurizer low pressure. 2. Pressurizer high level. 3. Reactor coolant system low flow, UV, and UF. 4. Turbine tripped.
P-8	3-Loop Flow Permissive	Power Range < 39%.	2/4 Channels.	Automatically blocks the single loop low flow reactor trip.
P-9 (Not on all plants)	Turbine Trip/Reactor Trip Permissive	Power Range < 50%.	2/4 Channels.	Blocks reactor trip on turbine trip below 50%.
P-10	Nuclear At-Power Block Permissive	Power Range > 10%.	2/4 Channels.	1. Opens contacts to SR high voltage power supply. 2. Enables BLOCK switches to allow the operator to block IR high flux and rod stop. 3. Permits operator to block PR low setpoint. 4. Input to P-7.
P-11	Pressurizer SI Block Permissive	Pressurizer Pressure < 1920 psig.	2/3 Channels.	Enables BLOCK switches to allow the operator to block low pressurizer pressure SI signal.

Table 12-3
SUMMARY OF PROTECTION GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Functions
P-12	Low-Low T_{avg}	T_{avg} < 540 °F.	2/4 Channels.	1. Enables BLOCK switches to allow the operator to block high steam flow SI signal. 2. Input to high steam flow SI logic. 3. Blocks steam dump valves at 540 °F. Operator may bypass the interlock on three of the cooldown valves.
P-13	Turbine At-Power Permissive	Turbine Power < 10%.	1/2 Channels.	Input to P-7.
P-14	SG High Level Override	Steam Generator Narrow Range Level > 78%.	2/3 per S/G on 1/4 S/G's	1. Closes main feedwater regulating and bypass valves. 2. Trips all main feed pumps. 3. Trips main turbine. 4. Closes all main feedwater isolation valves.

Table 12-4
SUMMARY OF CONTROL GRADE INTERLOCKS

Number	Name	Setpoint	Coincidence	Interlocks	Function
C-1	Intermediate Range Hi Flux Rod Stop	Amps = 20% Power.	1/2 channels.	Blocked when IR trip is blocked. Bypassed when IR trip is bypassed.	Stops control rod outward motion
C-2	Power Range Hi Flux Rod Stop	103% Power.	1/4 channels	Individual channel can be bypassed at local cabinet	Stops control rod outward motion.
C-3	Overtemperature ΔT Rod Stop & Runback	3% below OTΔT Reactor trip setpoint.	2/4 channels	None.	Stops control rod outward motion and initiates a turbine runback.
C-4	Overpower ΔT Rod Stop & Runback	3% below OPΔT Reactor trip setpoint.	2/4 channels	None.	Stops control rod outward motion and initiates a turbine runback.
C-5	Low Power Interlock	15% turbine power (impulse pressure)	Selected channel.	None.	Stops control rod outward motion in Automatic only.
C-7	Loss of Load	-10% turbine power rate (impulse pressure).	One channel assigned.	Seals in. Must be reset.	Arms steam dumps in load rejection mode if C-9 is present.
C-8 (Not in plant if P-9)	Turbine Tripped	Stop valves closed Auto stop oil pressure <45 psig.	4/4 channels. 2/3 channels.	None.	Shifts steam dump T_{avg} control from load rejection mode to turbine trip mode. Arms steam dumps if C-9 is present.
C-9	Condenser Interlock	Circulating water pump breaker closed and vacuum > 17" Hg.	1/3 channel.	None	Ensures condenser is ready for steam dump operation.
C-11	Control Bank D Withdrawal Interlock	Control bank D >220 steps.	One channel assigned.	None.	Stops outward rod motion in Automatic only.

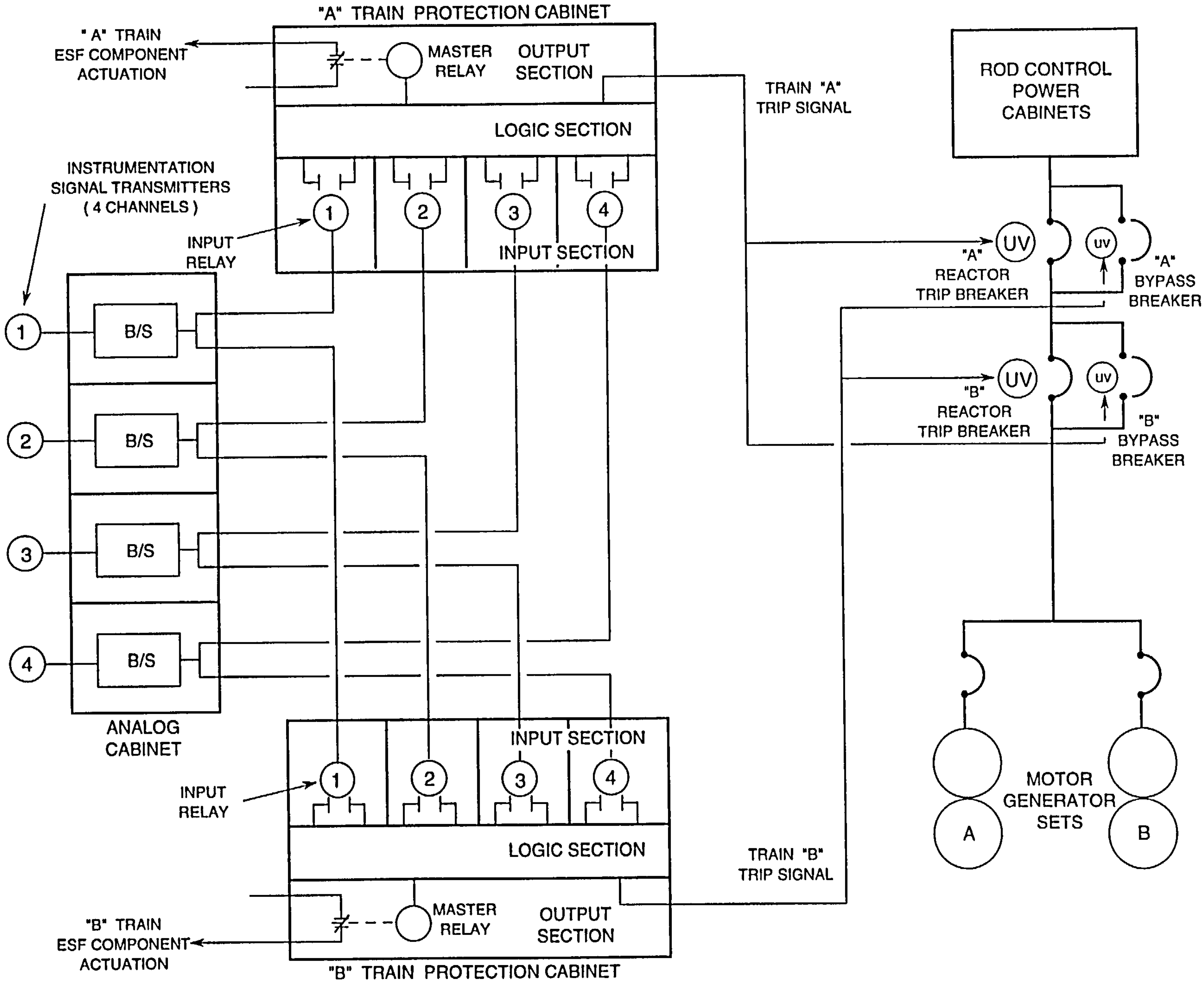

Figure 12-1 Reactor Protection System

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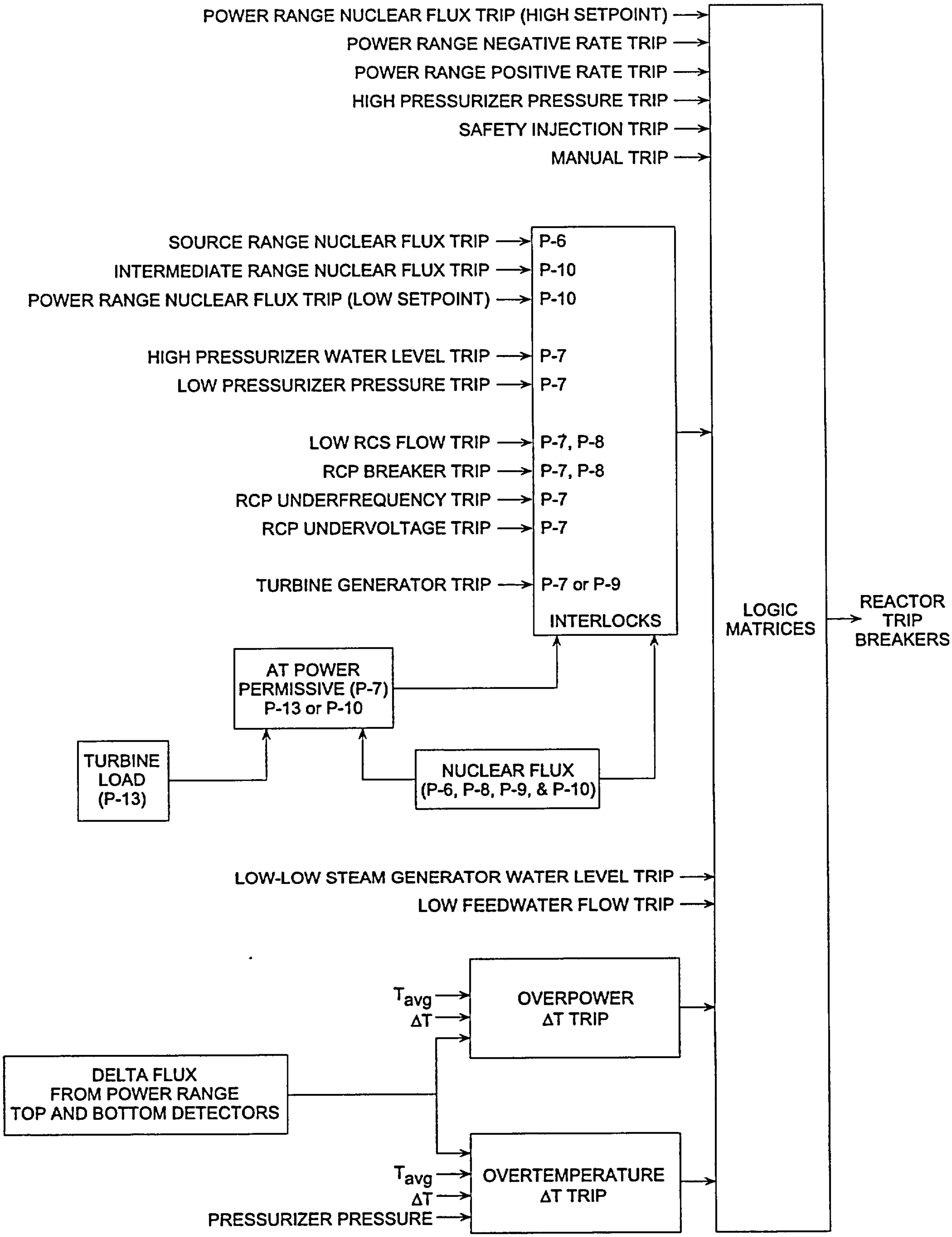

Figure 12-2 Reactor Protection System Block Diagram

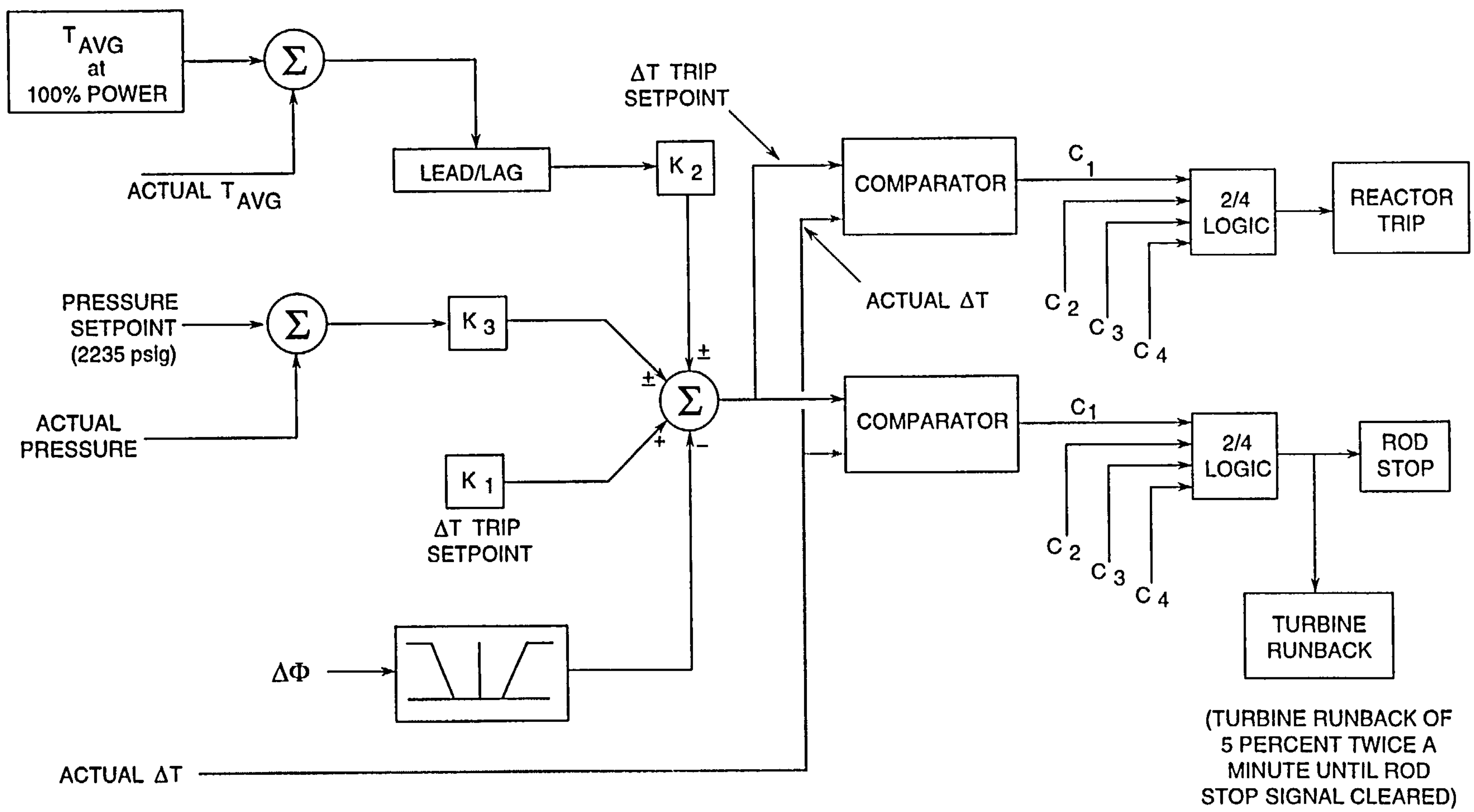

Figure 12-3 Overtemperature ΔT Channel Block Diagram

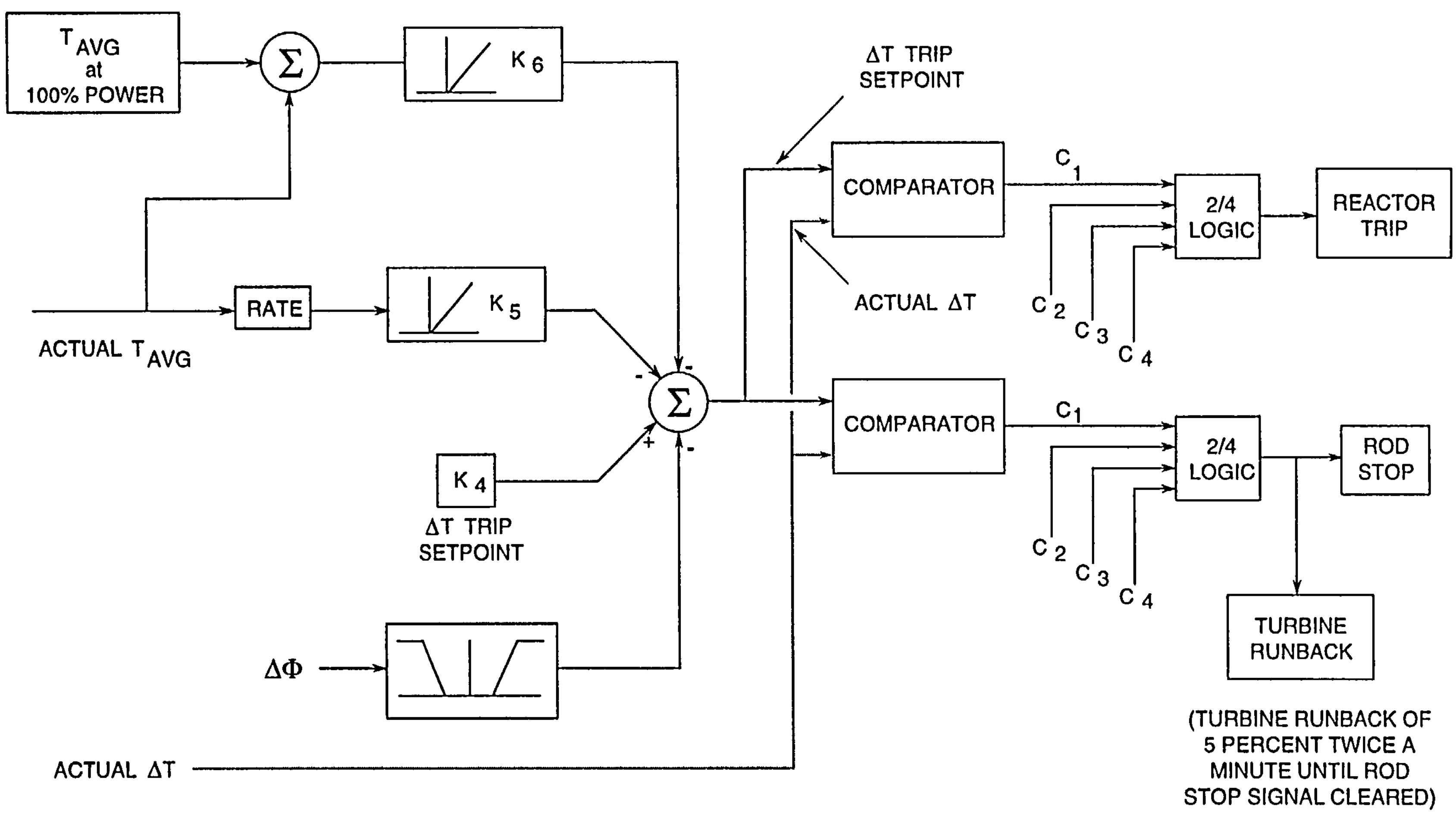

Figure 12-4 Overpower ΔT Channel Block Diagram

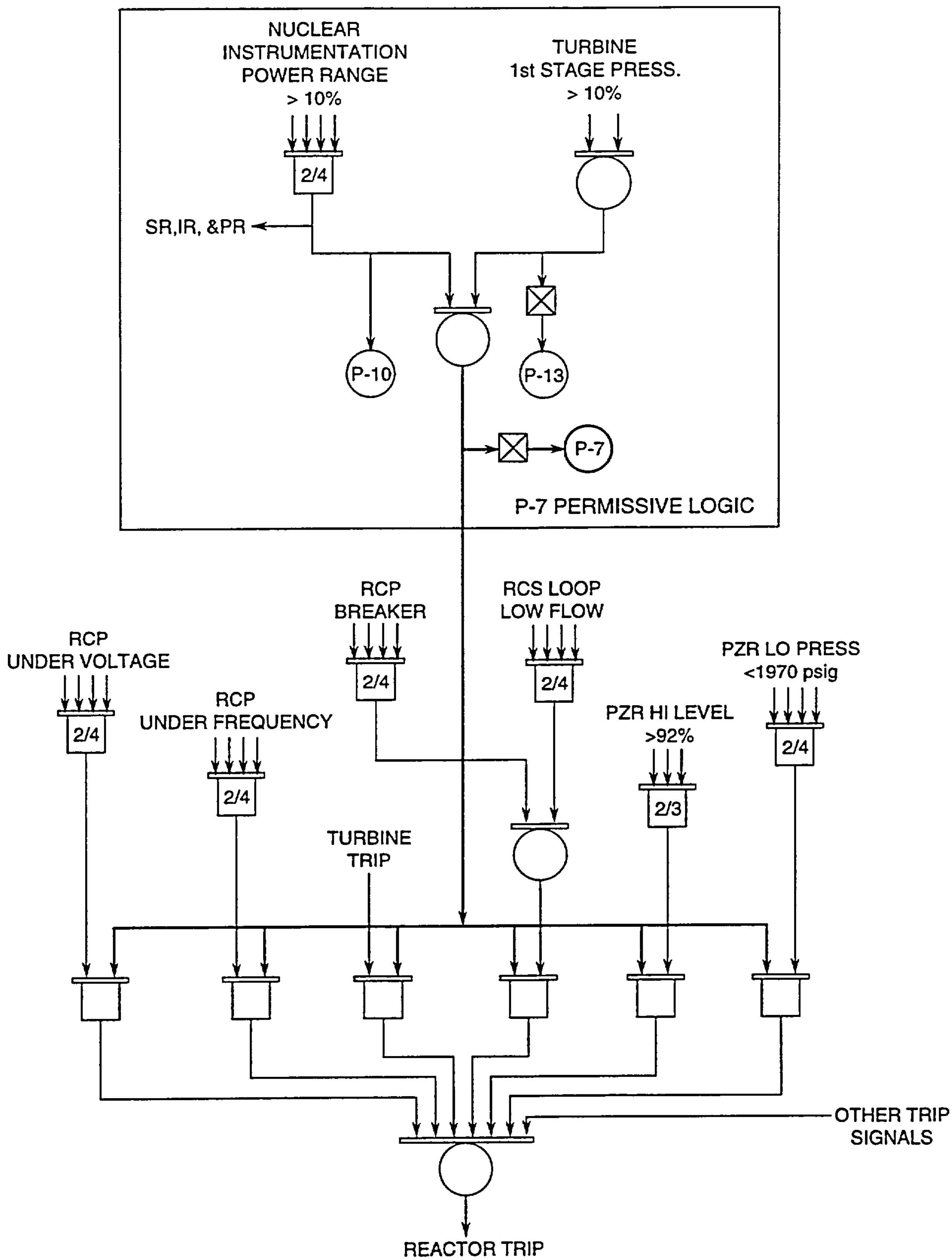

Figure 12-5 At Power Reactor Trip Logic

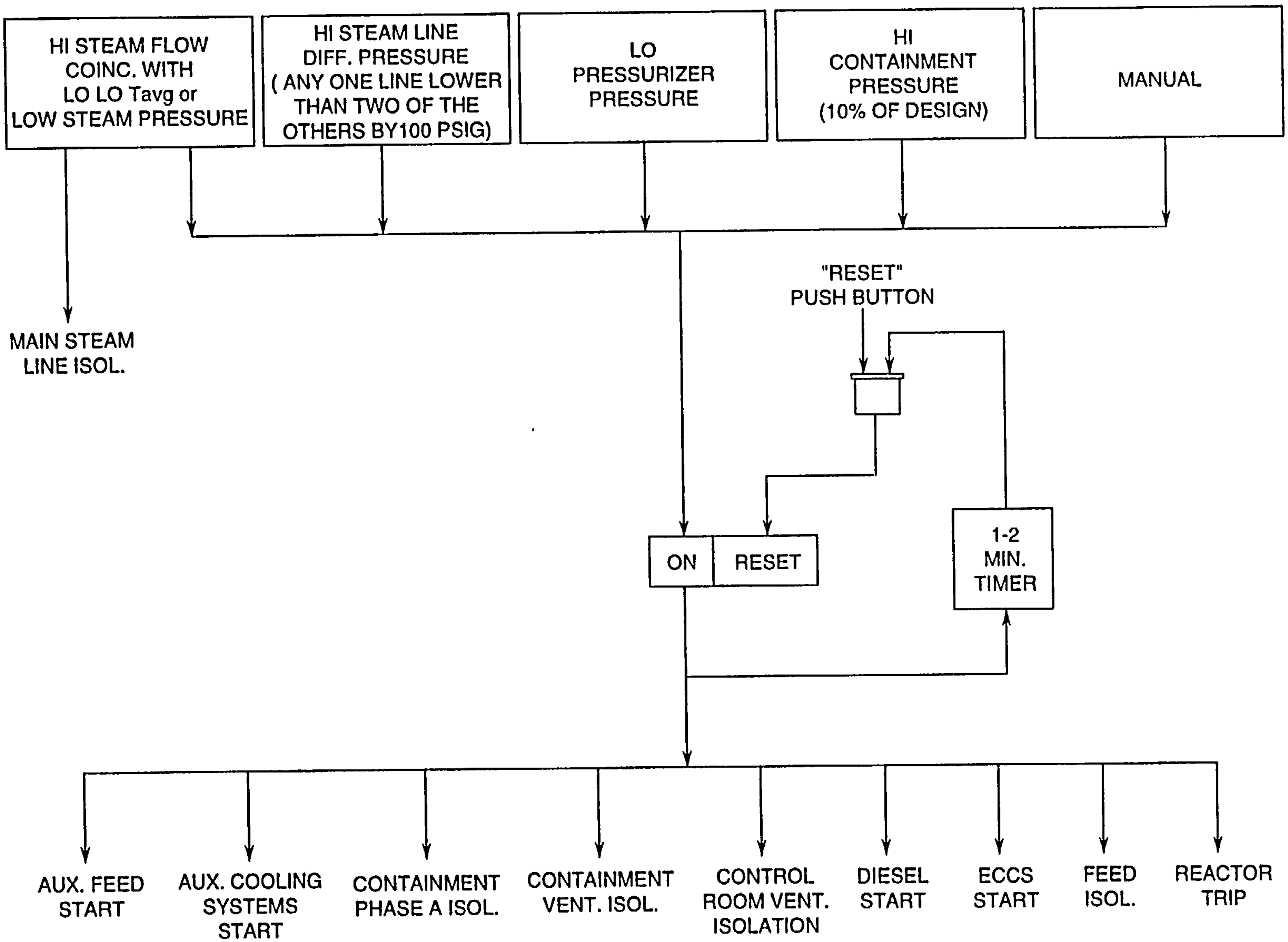

Figure 12-6 ESF Actuation Logic

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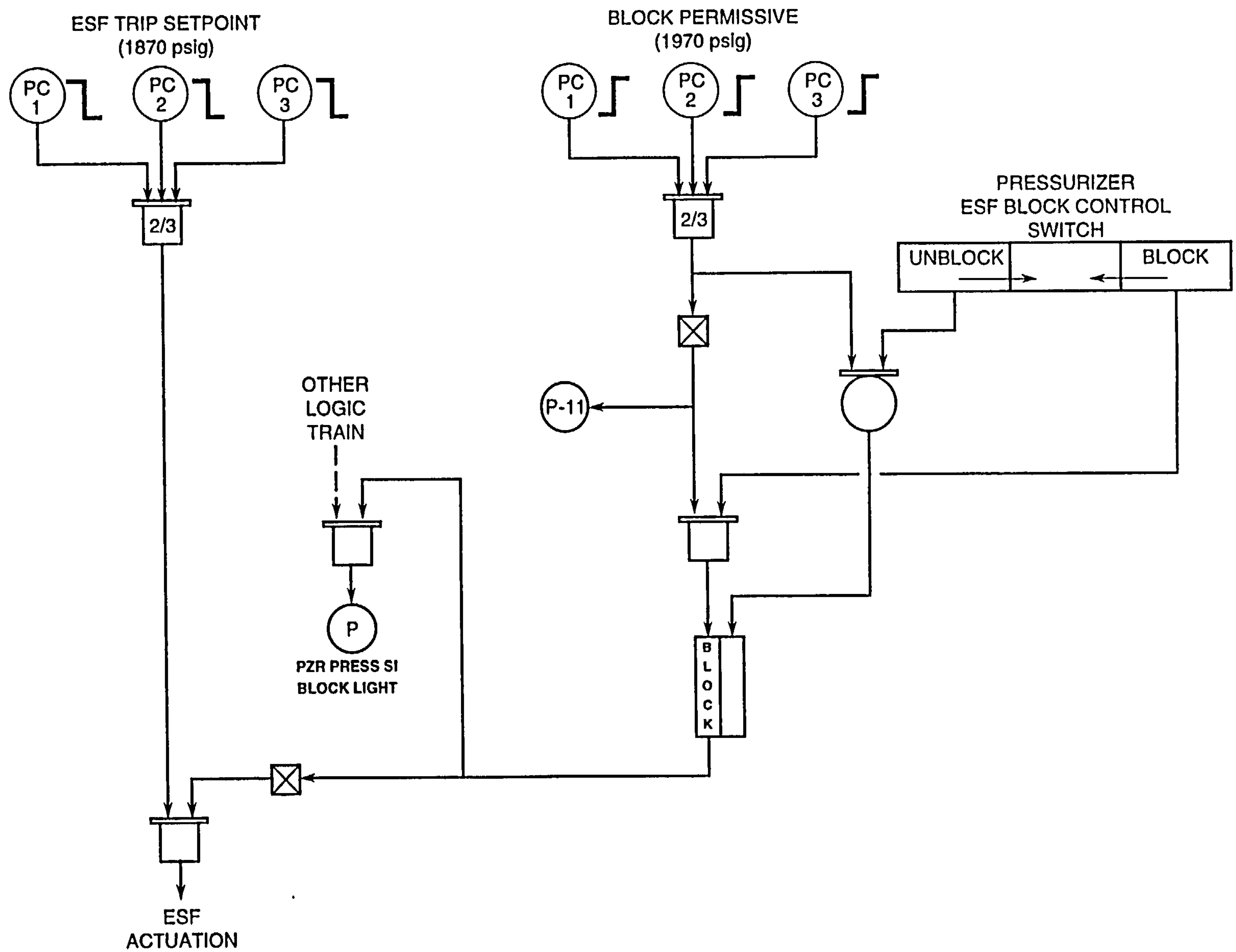

Figure 12-7 Low Pressurizer Pressure ESF Logic

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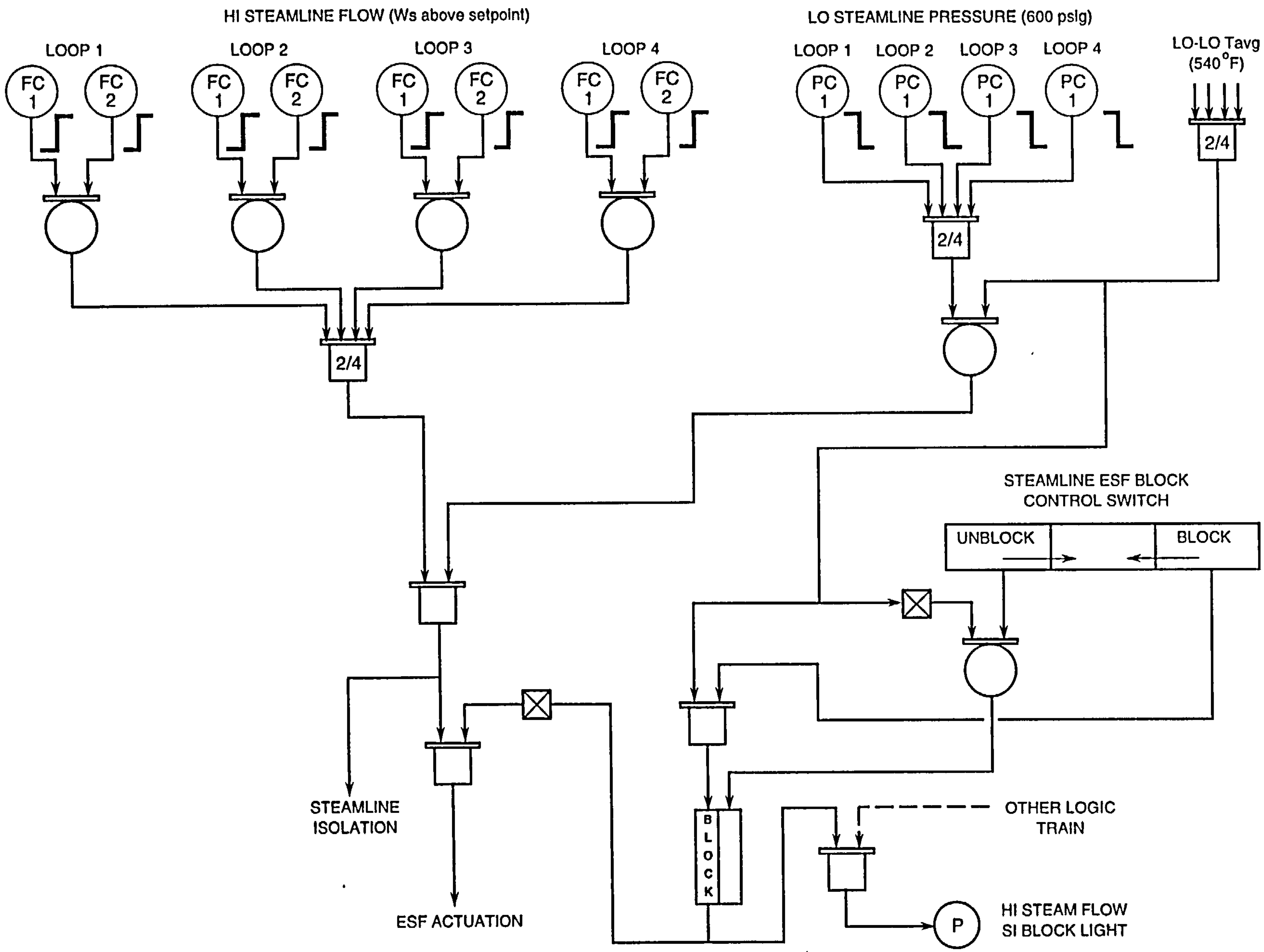

Figure 12-8 High Steamline Flow ESF Logic

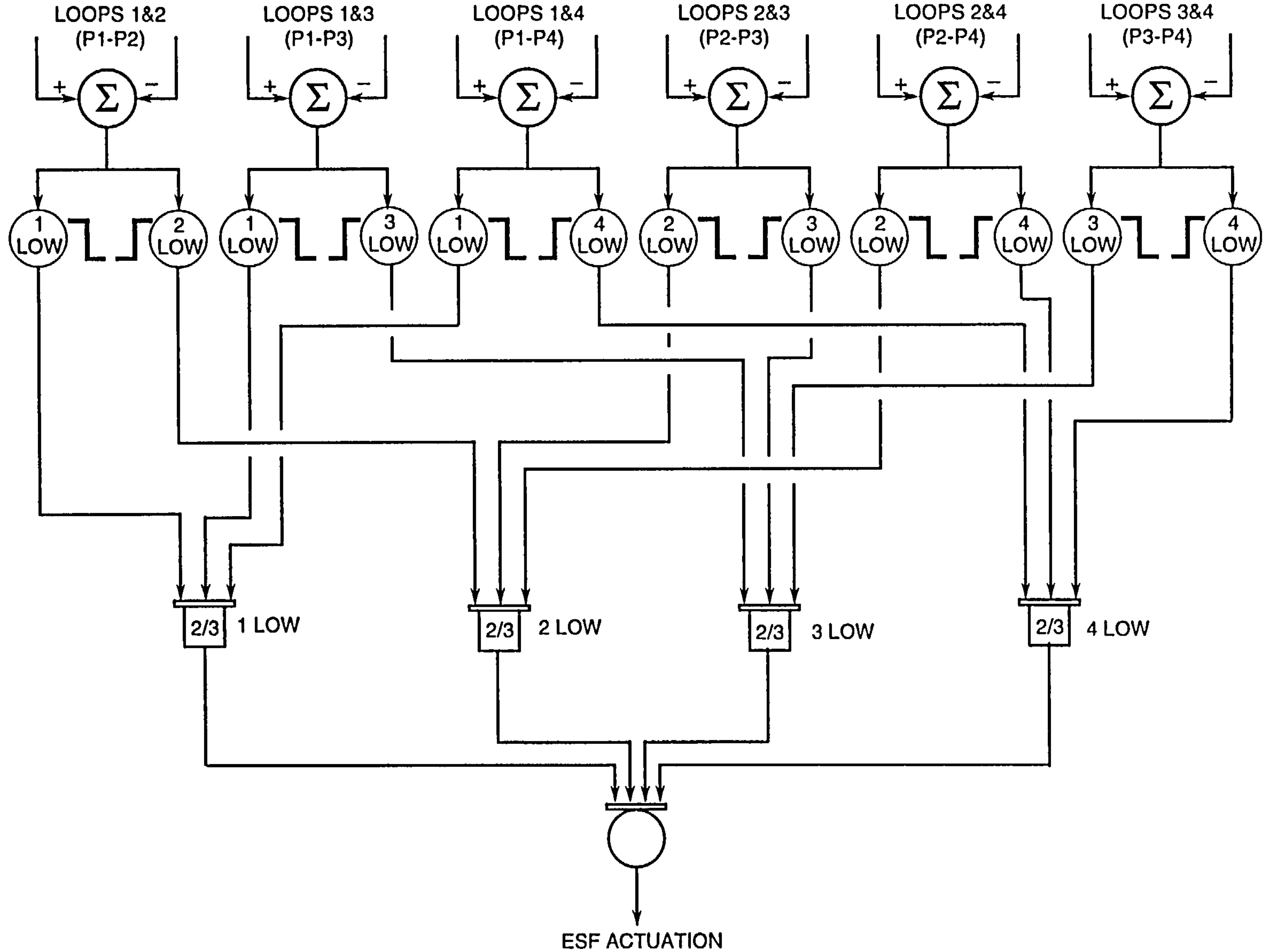

Figure 12-9 Steamline High Differential Pressure ESF Logic

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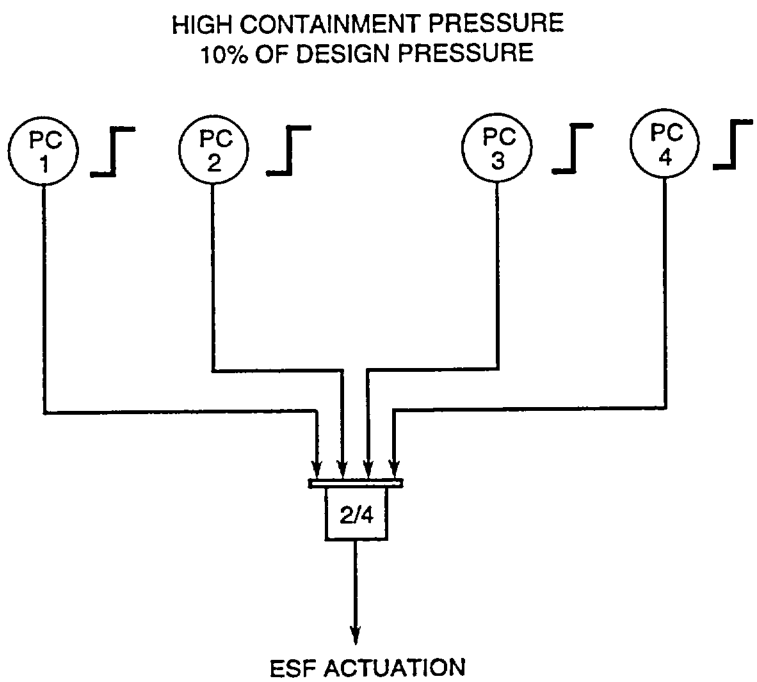

Figure 12-10 High Containment Pressure ESF Logic

Westinghouse Technology Manual

Chapter 13.0

Plant Air Systems

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13.0 PLANT AIR SYSTEMS

Learning Objectives:

1. Explain the purpose of the service and instrument air systems.
2. Describe the basic components of the service and instrument air systems.
3. Describe the instrumentation and controls associated with the air systems.
4. Explain the interconnections between the service and instrument air systems and support systems.

13.1 Introduction

Compressed air is used in many ways at a nuclear power plant. It can be used for cleaning, agitating, operating tools, or positioning valves. The instrument and service air systems provide this compressed air. The service air system is for general plant use while the instrument air system is used for operating pneumatic valves and instruments.

The compressed air system provides a reliable, continuous supply of air for control and instrument operations. The compressed air system consists of three compressors, three aftercoolers, three air receivers, alarms, control panels, and an instrument air filtering and drying unit. All components are located in the turbine building.

The air receivers are connected to a common header which branches into one instrument air header and one service air header. The filter and dryer unit is provided only for the instrument air header.

13.2 System Description

The compressed air system, consisting of the instrument air and service air systems, is comprised of three compressors, three aftercoolers, three air receivers, and instrument air filtering and drying equipment as shown on Figure 13-1. Each compressor takes a suction from inside the turbine building through its own air filter and discharges the compressed air to one of three air receivers which stabilize the compressor pulsations. During normal plant operation, one of the compressors is selected for continuous operation, while the other two compressors serve as standby units and start automatically if the operating compressor cannot meet system demand. The cooling water for the compressors is supplied from the service water system.

The air receivers are connected to a common compressed air header which branches into one instrument air header and one service air header. Each air header supply branches into lines which supply instrument air and service air to all parts of the plant.

The service air header supplies service air to outlets located throughout all areas of the plant. Each service air line penetrating containment has one locked closed globe valve on each side of the containment penetration. These valves are opened only when service air usage is required inside containment. They remain in the locked position when not in use to prevent the possibility of any containment air from contaminating and penetrating into the service air line in the event of containment being at a higher pressure than the service air supply.

Compressed air for instrument air passes through one of the two parallel instrument air filtering and drying units before being distributed to the instrument air piping system. Each unit is equipped with one prefilter, an air dryer assembly, and one afterfilter connected in series. This filtering and drying equipment allows cleaning and drying of the instrument air prior to use in order to minimize malfunctions of pneumatic instruments and valves due to dirt or oil particles in the air.

All instrument air lines penetrating containment have isolation valves located outside the containment, which are installed in series which check valves located inside the containment. These valves will prevent releases from containment in the event of a failure of the compressed air system, leaving the remaining air to supply vital systems in the auxiliary and containment buildings.

13.3 Component Description

13.3.1 Air Compressors

The air compressors are reciprocating, non-lubricated, water cooled, horizontal opposed piston, two stage, motor-driven units. Each of the compressors is rated to deliver 525 standard cubic feet per minute at a 150 psig discharge pressure. The compressors are sized so that each can supply sufficient air for the average instrument air requirements. Two of the compressors are powered from Class 1E busses. The third compressor is powered from a non-class 1E bus. There are three indicating lights for each compressor indicating AUTO (white), RUN (red), and STOP (green). The air compressors are cooled by service water during normal conditions. The compressors powered from the 1E busses are stripped on a safety injection signal. They may then be realigned to the busses manually.

13.3.2 Aftercooler

Associated with each compressor is an aftercooler to cool the flow of air to 110°F. The aftercoolers are air to water heat exchangers cooled by service water.

13.3.3 Air Receiver

Compressed air from the outlet of each aftercooler flows into its associated air receiver. The air receivers reduce pressure pulsations caused by the reciprocating air compressors and serve as a storage volume. They will supply a limited amount of compressed air following a compressor failure. Each air receiver is sized to provide approximately 30-seconds of instrument air at rated flow. This would provide sufficient time for the standby compressor to come up to rated pressure while the system pressure decreases from 125 psig to no less than 80 psig. The air receivers are designed for 150 psig.

13.3.4 Dryer/Filter Train

The instrument air system contains a dryer /filter train arrangement to provide dry, clean air to the instrumentation. The train consists of a series arrangement of two parallel prefilters, two parallel dual tower dryer units, and two parallel afterfilters. Only one of the parallel components is used at a time. This allows cleaning or changing of filters during system operation by diverting air flow through the parallel filter. Each air dryer consists of an interconnected set of two desiccant chambers. Air flow is automatically alternated through each chamber to permit the simultaneous drying of air in one chamber and the drying of air desiccant in the other chamber. Drying of the desiccant is accomplished by purging dry air through the chamber.

13.3.5 Accumulators

Several air operated valves in the plant are vital to plant safety. To ensure extended operation of these valves upon a loss of power, accumulators are provided to supply nitrogen gas in place of the air (Figure 13-2). There are five carbon steel accumulators provided to operate three different groups of valves. The valve groups are:

1. Auxiliary feedwater control valves (supply from turbine driven pump),
2. Main steam atmospheric relief valves, and
3. Main feedwater control valves.

Four accumulators are provided to supply nitrogen as a backup for the air supply to auxiliary feed flow control valves (turbine driven pump) and the main steam atmospheric relief valves. A separate nitrogen accumulator is provided as a backup for the main feedwater control valves. The operation of these valves and the accumulators is discussed in the associated chapters.

13.3.6 Instrumentation and Control

The air compressors and associated equipment are provided with local control panels. Each control panel consists of temperature and pressure switches, indicators, and automatic protection devices. Equipment status is indicated in the control room by a series of indicating lights. Indications and alarms are also provided for air system header pressure. Local pressure, temperature, and moisture indicators are provided on the local panel for each drying unit.

Continuous control room indication of the pressure of each safety related accumulator is provided. Local pressure indicators are also provided downstream of each accumulator pressure reducing valve to permit local monitoring of system pressure. A list of alarms associated with the air compressors and dryers are listed in Table 13-1.

Table 13-1
Air System Alarm Setpoints

	Alarm Setpoint
Compressor	
Main header low pressure, psig	112
Lo oil pressure, psig	5
Hi aftercooler disch. air temp., °F	290
Hi cooling water temperature, °F	145
Hi 2nd stage disch. Air temp., °F	395
Lo cooling water pressure, psig	7
Lo suction press., in. H_2O gauge	60
Dryer	
High prefilter Δp, psid	4
High afterfilter Δp, psid	4
High dryer package Δp, psid	8
High dryer outlet pressure, psig	106

13.4 System Interrelationships

13.4.1 System Interfaces

Service air is supplied throughout the plant for service and maintenance operation. Instrument air is provided throughout the plant to operate diaphragm valves and control devices. The instrument air system is physically connected to every major system in the plant. The following systems are needed to support the service and instrument air systems:

1. Service water system - used to cool the air compressors and aftercoolers during normal operation,

2. Essential service water system - used in the event of loss of offsite power. Cooling will be provided for the compressors which receive power from class 1E busses, and

3. AC electrical power systems - provide control power and motive power to the compressors.

The hydrogen purge system (Chapter 5.2) consists of two containment isolation valves and ductwork that delivers containment air to the auxiliary/fuel building emergency exhaust system. If required, it would be manually initiated about nine days after a loss of coolant accident, at which time the maximum hydrogen should be about 3.0 volume percent. Makeup air to the containment would be provided by the instrument air penetrations or an air bottle that could be hooked up to several containment penetrations. The system is designed to vent 100 standard cubic feet per minute.

13.4.2 System Operation

One of the three air compressors is normally available for service at all times. The other air compressors are placed in a standby mode. In the event of a loss of the operating compressor or during heavy load demands, the standby compressor will automatically start (header pressure of 115 psig). If pressure continues to drop (110 psig), the second standby compressor will come on the line. Automatic starts occur only on low header pressure. An unloader valve automatically loads and unloads the on-line compressor in response to small system pressure variations. This minimizes the amount of compressor starts and stops required to maintain pressure. The compressor automatically shuts down after running unloaded for 10 minutes. The sequence of compressor starts can be varied to permit equal operating time for all three air compressors.

The discharge line for each air receiver is connected in parallel to a common header. The service air takes its supply from the common header. The service air header directs the distribution of service air to various outlets throughout the plant. The instrument air system takes its supply from the common header to the filter/dryer train. The filter/dryer train processes the air to the required cleanliness and dew point.

The service air line is provided with an isolation valve that will automatically isolate the service air header when pressure falls below 110 psig. This arrangement is provided to direct all the compressed air to the instrument air header in the event of excessive demand. All air compressors will automatically start if the pressure in the instrument air header drops to 105 psig. This feature is provided to preclude a complete loss of air should the normal starting sequence fail. The accumulators start supplying nitrogen to the main feed, main steam, and auxiliary feed valves when instrument air header pressure drops below 100 psig.

13.5 Summary

The service and instrument air systems supply low pressure air (122 psig) for several functions around the plant. The service air system is for general plant use. The instrument air system is used for operating pneumatic valves and instruments. Both the service and instrument air systems have the same supply.

The instrument air system has two parallel prefilters, dual tower dryer units, and afterfilters to supply it with clean air. Under normal operations, one of the three compressors will supply all needs. When systems have heavy use, the other two compressors are available. Air operated safety valves (main feed and turbine driven auxiliary feed valves and main steam atmospherics) are provided with accumulators to supply nitrogen to valves in the event of failure of the instrument air system.

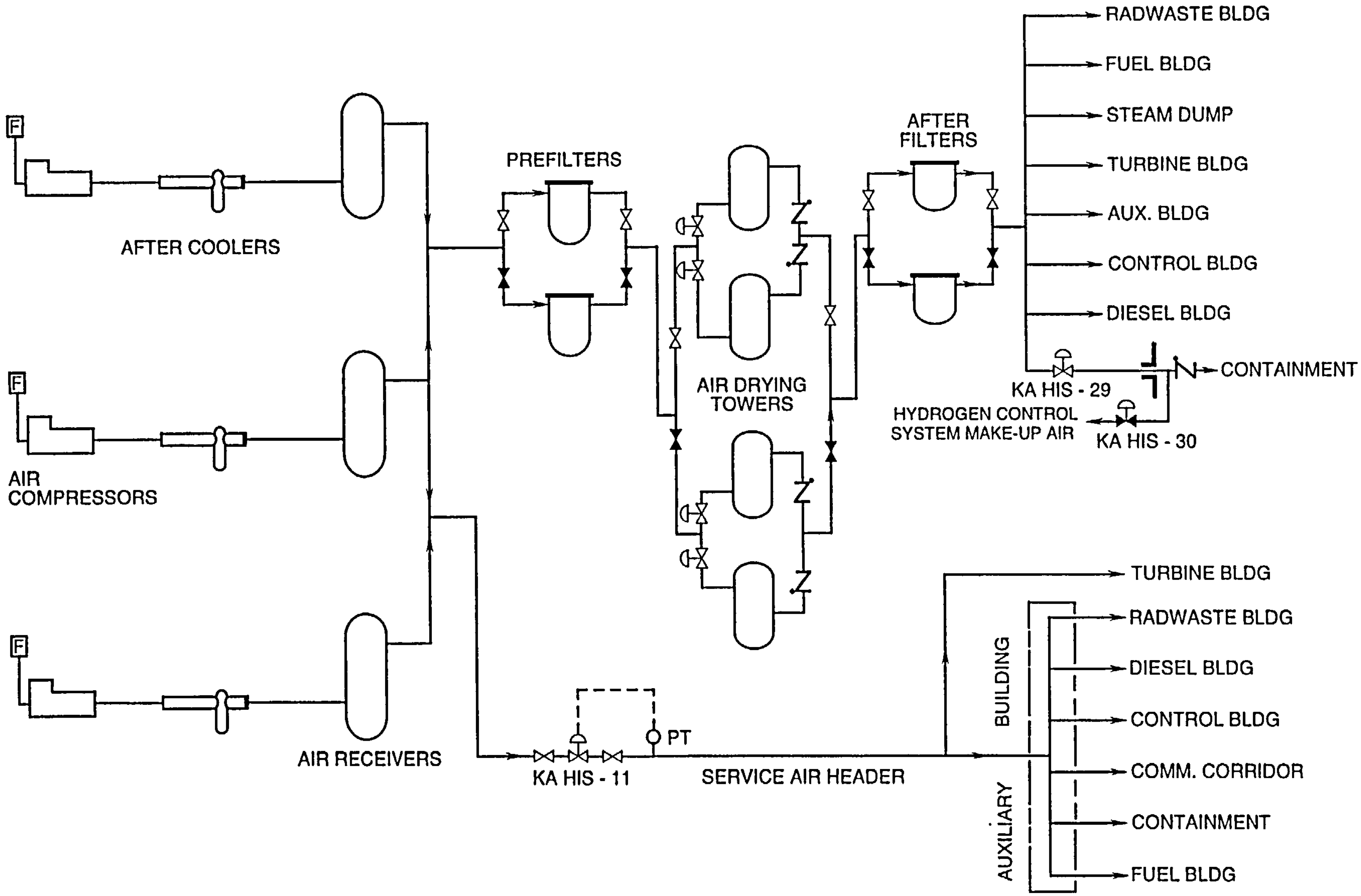

Figure 13-1 Typical Air System

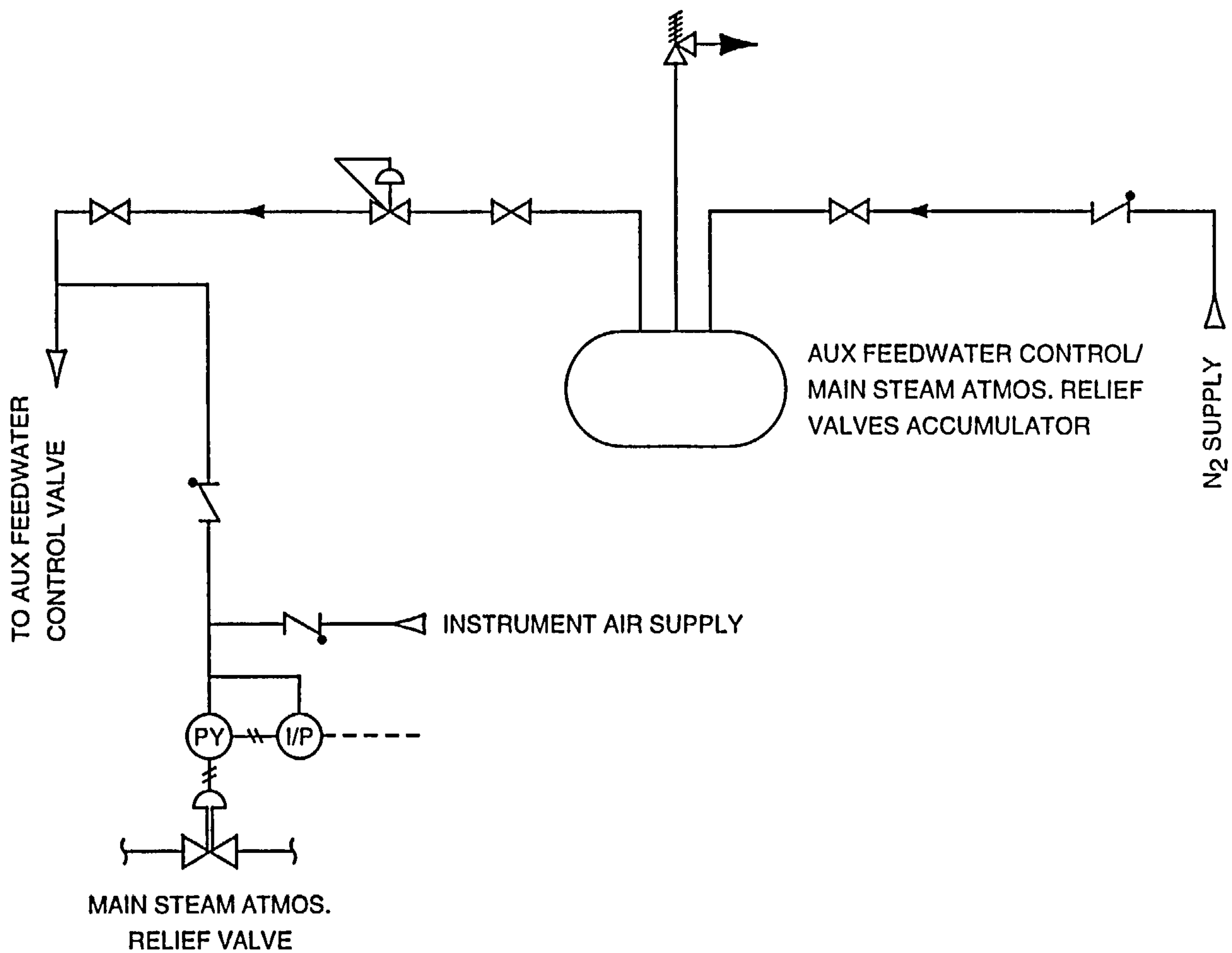

Figure 13-2 Nitrogen Accumulator Backup Supply

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Chapter 14.0

Refueling Systems

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14.0 REFUELING SYSTEMS

Learning Objectives:

1. State the functions of each of the following fuel handling system equipment:

   a. Spent fuel pool bridge crane,
   b. New fuel elevator,
   c. Fuel transfer canal,
   d. Manipulator crane,
   e. Rod cluster control assembly change fixture,
   f. Reactor vessel stud tensioner,
   g. Conveyor car, and
   h. Upenders.

2. State the reasons for handling spent fuel under water.

3. State the purpose of the spent fuel pit cooling system.

14.1 Introduction

Spent fuel is handled under water from the time it leaves the reactor vessel until it is placed in a cask for shipment from the site. The water provides an effective, economical, and transparent radiation shield as well as a reliable medium for decay heat removal. Boric acid is added to the water to ensure subcritical conditions during refueling.

The fuel handling facilities (Figures 14-1 and 14-2) are generally divided into two areas:

1. The refueling cavity and the fuel transfer canal, which are flooded only during the refueling shutdown, and
2. The fuel storage pit, which is kept full of water and is always accessible to operating personnel.

These two areas are connected by the fuel transfer tube through which an underwater conveyor or fuel transfer system carries the new fuel into the plant (reactor) containment and spent fuel into the fuel handling building.

In the refueling cavity, fuel is removed from the reactor vessel by a refueling machine, transferred through the water, and placed in the fuel transfer system. In the fuel handling building, the fuel is removed from the transfer carriage and placed in storage racks in the fuel storage pit by using a manually operated spent fuel assembly handling tool suspended from an overhead bridge crane. After a sufficient decay period, the spent fuel can be removed from the fuel racks and loaded into a shipping cask for removal from the site.

New fuel assemblies normally arrive at the site shortly before refueling is to commence. Following site receipt inspection to check for any possible shipping damage, the new assemblies are lowered into the fuel storage pit by means of the new fuel elevator and are placed underwater in the storage racks. During the refueling operation, the new assemblies are transported from their storage locations in the pit to the fuel transfer system by means of the fuel handling machine and the spent fuel handling tool.

14.2 Fuel Handling Facilities

Fuel handling facilities consist of a refueling cavity and fuel storage pit as previously defined.

14.2.1 Refueling Cavity

The refueling cavity is a reinforced concrete structure. When filled with borated water for refueling, it forms a pool above the reactor. The cavity is filled to a depth of approximately 24 feet of water when a fuel assembly is being transferred between the reactor and the fuel transfer system. This limits radiation at the surface of the water to acceptable levels during those brief periods. Radiation levels as a function of water depth in the refueling cavity for a 12-foot active fuel assembly are given in Table 14-1.

Table 14-1
Radiation Levels as a Function of Water Depth Above Fuel Assembly

Water Depth Above Top of Fuel Assembly*	Radiation Level (mr/hr)
9'6"	2.5
9'0"	5.2
8'6"	10.9
8'0"	23..0
7'6"	47.0
7'0"	99.0
6'6"	206.0

*Distance from top of fuel assembly to top of active fuel length is one foot.

The reactor vessel flange is permanently sealed to the refueling cavity floor by means of a welded stainless steel ring (Figure 14-3). This permanent concrete-to-vessel cavity seal prevents leakage of refueling water from the cavity. Cooling air ventilation for the reactor vessel annulus is routed through the exit ductwork located below the seal.

The refueling cavity is large enough to provide underwater storage space for the reactor upper and lower internals and for miscellaneous refueling tools.

14.2.2 Fuel Transfer Canal

The fuel transfer canal is a passageway that extends from the refueling cavity to the inside surface of the reactor containment. The canal is formed by concrete shielding walls extending upward to the same elevation as the refueling cavity. A portion of the floor of the canal is at a lower elevation that the refueling cavity. This provided the extra depth needed for the fuel system upending device and the rod cluster control changing fixture located in the canal. The transfer tube, which connects the fuel transfer canal to the fuel building, is sealed at both ends except during refueling.

14.2.3 Fuel Storage Pit

The fuel storage pit provides for the underwater storage of spent fuel assemblies and new fuel assemblies in the fuel storage racks. It is constructed of reinforced concrete, and the entire interior surface is lined with stainless steel plate. Because there are no gravity drains in the pit, it cannot be drained accidentally. Cooling to remove residual decay heat from the spent fuel is provided by a spent fuel pit cooling and cleanup system.

Spent and new fuel assemblies are handled manually by a spent fuel assembly handling tool suspended from an overhead hoist and manipulated by an operator standing on a movable bridge over the pit.

Fuel assembly storage racks to accommodate a minimum of 1-1/3 times the number of assemblies in a core are located on the pit floor. Fuel assemblies are placed in vertical cells, continuously grouped in parallel rows. The racks are designed to preclude insertion of fuel assemblies in other than the prescribed locations, thereby maintaining the necessary spacing between assemblies. The racks thus provide a subcritical geometric array. Borated water is used to fill the pit to a concentration matching that used in the refueling cavity during refueling, and to a depth sufficient to allow transfer of the fuel assemblies while providing adequate shield water cover.

14.2.4 Decontamination Facilities

Equipment and cask cleaning areas are located adjacent to the spent fuel storage pit. In the equipment area, fuel handling equipment and other tools can be cleaned and decontaminated. In the cask cleaning area, the outside surfaces of the cask are decontaminated by using steam, water, detergent solutions, and manual scrubbing to the extent required. When determined to be clean, the cask is removed by crane for loading onto a truck or railroad car.

14.3 Refueling Equipment

The fuel handling equipment consists of a number of tools used to open and close the reactor and to move fuel from one location to another. These tools are described in the following paragraphs.

14.3.1 Reactor Vessel Head Lifting Device

The reactor vessel head lifting device consists of a welded and bolted structural steel frame with suitable rigging to enable the reactor containment crane to lift the head and store it during refueling operations. The lifting device is permanently attached to the reactor vessel head. Attached to the head lifting device are the monorail and hoists for the reactor vessel stud tensioners.

14.3.2 Reactor Internals Lifting Device

The reactor internals lifting device is a structural frame suspended from the overhead crane. The frame is lowered onto the top support plate of the upper internals, and is connected to the support plate by three breech-lock-type connectors having long tubes extending up to an operating platform on the lifting device. Bushings on the frame engage guide studs in the vessel flange to provide precise guidance during removal and replacement of the internals package. The internals lifting device is also used to remove the lower internals structure approximately once every 10 years.

14.3.3 Refueling Machine (Manipulator Crane)

The refueling machine transfers fuel assemblies within the core and between the core and the fuel transfer system conveyor carriage. It is a rectilinear bridge and trolley crane with a stationary vertical mast extending down into the refueling water. The bridge spans the refueling cavity and runs on rails set into the floor along the edge of the refueling cavity. The bridge and trolley motions are used to position the vertical mast over a fuel assembly in the core.

A movable mast with a pneumatic gripper on the end is lowered down from inside the stationary mast to grip the fuel assembly. The movable mast is long enough so that the upper end is still contained in the stationary mast when the gripper end contacts the fuel. A winch mounted on the trolley raises the gripper and fuel assembly up into the stationary mast. Fuel is transported by the mast to its new position.

All refueling machine controls are mounted on a console on the trolley. The bridge is positioned on a coordinate system laid out on the bridge and trolley rails. The electrical readout system on the console indicates the position of the bridge. The trolley is positioned on the bridge structure with the aid of a scale, which is read directly by the operator at the console.

The refueling machine is supplied with an electrical monorail hoist mounted above the bridge walkway for use with long-handled manual tools. The hoise is suspended from a beam running the length of the bridge.

The drives for the bridge, trolley, and main boom winch are variable speed, including a separate inching control on the winch. The main boom and trolley drives are variable to 20 feet per minute, and the bridge drive is variable to 40 feet per minute. The overhead monorail hoist is driven at two speeds, 7 and 22 feet per minute.

Electrical interlocks and limit switches on the bridge and trolley drives protect the equipment. In an emergency, the bridge, trolley, and winch can be operated manually by using a handwheel on the motor shaft.

The suspended weight on the gripper tool is monitored by an electrical load cell indicator mounted on the control console. A load in excess of 110 percent of a fuel assembly weight automatically stops the winch drive from moving in the up direction. The gripper is interlocked through a weight-sensing device and also a mechanical spring lock so that it cannot be opened accidentally when supporting a fuel assembly. Numerous other safety features are incorporated in the manipulator crane design.

Suitable restraints are provided between the bridge and trolley structures and their respective rails to prevent derailing due to the maximum potential earthquake. The refueling machine is designed to prevent disengagement of a fuel assembly from the gripper under the maximum potential earthquake.

14.3.4 Fuel Handling Machine (Spent Fuel Pool Bridge Crane)

The fuel handling machine is a wheel mounted bridge that spans the fuel storage pit. It carries an electric monorail hoist on an overhead structure. Fuel assemblies are moved within the fuel pit by means of long-handled tools suspended from the hoist. Both the bridge and the hoist drives can operate at two speeds. The hoist travel and tool length are designed to limit the maximum lift of a fuel assembly to a safe shielding depth.

14.3.5 Rod Cluster Control Changing Fixture

The rod cluster control (RCC) changing fixture is mounted on the fuel transfer canal wall and is used for periodic RCC element inspections and for transfer of RCC elements from one fuel assembly to another. The fixture consists of two main components: a guide tube mounted to the wall for containing and guiding the RCC element, and a wheel-mounted carriage for holding the fuel assemblies and positioning fuel assemblies under the guide tube. The guide tube contains a pneumatic gripper on a winch that grips the RCC element and lifts it out of a fuel assembly. By repositioning the carriage, a new fuel assembly is brought under the guide tube, and the gripper lowers and releases the RCC element. The refueling machine loads and removes the fuel assemblies into and from the carriage.

14.3.6 Upper Internals Storage Stand

The upper internals storage stand is a structural stainless steel fixture mounted to the floor of the refueling cavity and is used to support the upper internals structure from its top flange when removed from the reactor vessel. For alignment purposes, guide studs are provided to mate with the bushings on the internals lifting rig. During refueling, the stand is underwater.

14.3.7 Reactor Vessel Stud Tensioner

Stud tensioners are employed to release and secure the head closure joint at every refueling. The stud tensioner is a hydraulically operated device that uses oil as the working fluid. The device permits preloading and unloading of the reactor vessel closure studs at cold shutdown conditions. Three tensioners are provided and are applied simultaneously to three studs located 120 degrees apart. A single hydraulic pumping unit operates the tensioners, which are hydraulically connected in series. The studs are tensioned to their operational load in three steps to prevent high stresses in the flange region and unequal loadings in the studs. Relief valves on each tensioner prevent overtensioning of the studs due to excessive pressure. Micrometers are provided to measure stud elongation after tensioning.

14.3.8 Stud Tensioner Handling Device

The stud tensioner handling device is used to suspend the stud tensioner from the support structure on the reactor vessel head lifting rig during installation or removal of the reactor vessel studs.

14.3.9 Fuel Transfer System

The fuel transfer system incorporates an underwater conveyor car that runs on tracks extending from the fuel transfer canal through the transfer tube in the containment wall and into the fuel building. The car is driven by a pusher arm connected to two continuous roller chains. The roller chains are driven by an electric motor mounted near the operating floor of the fuel storage pit and connected to the chain drive sprockets by a vertical drive shaft.

Two center-pivoted fuel assembly containers (Figure 14-4) are attached to the transfer car by means of the pivot. The containers and car travel as a single unit, and the unit is positioned against a mechanical stop. The containers are raised against another mechanical stop by a lifting arm attached to one of two stationary water hydraulic cylinders. The two hydraulic cylinders, one located in the refueling cavity and the other in the fuel building, are operated by a hydraulic power unit mounted at the operating deck level. The power unit is a positive displacement pump driven by an electric motor.

The conveyor car (upender) container accepts a fuel assembly in the vertical position. It is rotated to a horizontal position for passage through the fuel transfer tube and is then rotated to a vertical position for unloading. The upending operation is the same in both the fuel building and the containment transfer canals.

During plant operation, the conveyor car is stored in the fuel building. A gate valve in the transfer tube on the fuel building end is closed to seal the reactor containment. The terminus of the tube inside the containment is seal by a blind flange.

14.3.10 Control Rod Drive Shaft Unlatching Tool

The control rod drive shafts are disconnected and reconnected to the rod cluster control assemblies by means of the control rod drive shaft unlatching tool (Figure 14-5). This tool is suspended from the auxiliary hoist on the refueling machine and is operated from the bridge. The latching mechanism is pneumatically operated. All drive shafts are removed as a unit with the reactor vessel upper internals.

14.3.11 Spent Fuel Assembly Handling Tool

This tool is used to handle new and spent fuel in the storage pit. It consists of a gripping device on the end of a long tube suspended from the fuel pit auxiliary hoist. An operator on the fuel handling machine bridge guides and operates the tool.

14.3.12 Rod Cluster Control Thimble Plug Handling Tool

This long-handled, manually operated tool is used in the fuel transfer canal to remove and replace thimble plugs in fuel assemblies. When an RCC element is being transferred from one fuel assembly to another, a thimble plug is inserted in the fuel assembly from which the RCC was removed.

14.3.13 Primary Source Rod Insertion Guide

This is a disposable guide used to install the primary startup neutron sources in the fuel assembly. Because the primary source is radioactive, it must be handled remotely. The guide is placed in the fuel assembly top nozzle to guide the source rod into the proper thimble.

14.3.14 Burnable Poison Rod Assembly Handling Tool

This long-handled tool is used to transfer burnable poison rod assemblies between two fuel assemblies or a fuel assembly and inserts in fuel storage racks.

14.3.15 Irradiation Surveillance Capsule Handling Tool

This long-handled tool is used to reach down through openings in the reactor lower internals flange to remove the irradiation surveillance capsules from holder mounted on the neutron pads.

14.3.16 New Rod Control Cluster Handling Tool

This short-handled tool is used for the handling of new unirradiated rod control clusters in the fuel building and to facilitate inspection and insertion of new rod control clusters into new fuel elements.

14.3.17 New Fuel Assembly Handling Fixture

This short-handled tool is used to handle new fuel on the operating deck of the fuel building, to remove the new fuel from the shipping container, and to facilitate inspection and loading of fuel into the new fuel elevator.

14.3.18 Control Rod Drive Shaft Handling Fixture

This fixture is used during construction of the plant for initial installation of the control rod drive shafts.

14.3.19 Stud Hole Plugs

Unthreaded side-sealing stainless steel stud hole plugs are used to prevent refueling water from entering the reactor vessel closure stud holes. The expanding seal plug is placed into the counterbored upper portion of the stud hole with a handling tool. The plug is then mechanically expanded to force the dual elastomer seal rings against the counterbored stud hole wall to make the watertight seal. This sealing method eliminates the potential for galling of the stud hole threads.

14.3.20 Stud Hole Plug Handling Fixture

This is a small tool used to insert the stud hole plugs into the reactor vessel stud holes following stud removal.

14.3.21 Guide Studs

Three guide studs are inserted into the reactor vessel flange in vacated stud holes during refueling. The studs guide the closure head off and onto the vessel and the internals into and out of the vessel.

14.3.22 Load Cell

A load cell is inserted between the polar crane hook and the reactor internals lifting rig and between the polar crane hook and the head lifting rig to monitor the lifting force during removal of the internals and the head.

14.3.23 Crane Scales

The crane scales are load-measuring devices used to monitor the lifting forces of long-handled tools during refueling operations.

14.3.24 Refueling Machine Load Test Fixture

The load test fixture is a stainless steel mockup of the fuel assembly top nozzle anchored to the refueling cavity floor. The test fixture is used to check out the refueling machine prior to refueling.

14.3.25 New Fuel Elevator and Winch

The new fuel elevator and winch are used to lower new fuel assemblies to the bottom of the spent fuel pit, either for temporary storage in the fuel racks or placement in the transfer system for transfer to the reactor. The elevator is a box-shaped assembly with its top open and sized to house one fuel assembly.

14.3.26 Underwater Lights

An assembly of cable, cable reel, and underwater light fixtures is provided for illumination of the underwater working area. The cable reels are supported on the refueling machine or fuel handling machine.

14.4 Refueling Operation

The reactor is generally refueled by plant operating personnel. To perform the fuel handling operation, one supervisor and six technicians are necessary for each shift. Maintenance personnel are also employed to provide labor support during various phases of the refueling operation. This manpower requirement only applies to the fuel handling operation. Other plant and maintenance work in progress will require additional personnel. Licensed operators must also be in attendance in the control room, and health physics coverage is required.

Detailed instructions are made available for use by refueling personnel. These instructions, safety limits and conditions, and the design of the fuel handling equipment incorporate built-in interlocks and safety measures.

Prior to the initial fueling, preoperational checkouts of the fuel handling equipment are performed to verify the proper performance of the fuel handling equipment and to familiarize plant operating personnel with operation of the equipment. A dummy fuel assembly and RCC are utilized for this purpose.

Immediately prior to each refueling operation, the equipment is inspected for satisfactory operating condition. Certain components, such as the fuel transfer car and refueling machine, are operated at this time to test their performance prior to moving irradiated fuel.

Direct communication between the control room and the refueling machine should be available whenever changes occur in core geometry. This provision allows the control room operator to inform the refueling machine operator of any impending unsafe condition detected from the main control board indicators during fuel movement.

The refueling operation is divided into five major phases: preparation, reactor disassembly, fuel handling, reactor reassembly, and preoperational checks, tests, and startup. A general description of a typical refueling operation through the five phases is given in the following paragraphs.

14.4.1 Phase I - Preparation

1. The reactor is shut down and cooled to ambient conditions.

2. A radiation survey is made, and the containment is entered.

3. The fuel transfer equipment and refueling machine are checked out.

14.4.2 Phase II - Reactor Disassembly

1. The control rod drive mechanism cooling fans and air ducts are disconnected and moved to storage.

2. Control rod drive mechanism missile shield is removed and stored.

3. Reactor vessel head insulation is removed.

4. Control rod drive mechanism cables are disconnected.

5. Upper instrumentation thermocouple leads are disconnected. The thermocouple column protective sleeve is installed over the top of the support column.

6. Seismic support tie bars, cable tray assemblies, and missile shield support beams are removed.

7. Incore instrumentation thimble guides are disconnected at the seal table and extracted.

8. Reactor vessel head nuts are loosened using the stud tensioners.

9. Reactor vessel head studs and nuts are removed and stored.

10. Guide studs are installed in three stud holes. The remainder of the stud holes are plugged.

11. Vessel head lifting grid tripod is installed while final preparations are made for underwater lights, tools, and fuel transfer system. The blind flange of the tube enclosing the fuel transfer tube is removed.

12. Reactor vessel head is unseated and raised by the plant crane.

13. Reactor cavity is filled with borated water to the vessel flange.

14. Head is slowly lifted while water is pumped into the cavity. The water level and vessel head are raised simultaneously, keeping the water level just below the head.

15. Reactor vessel head is removed to a dry storage area.

16. Control rod drive shafts are unlatched using the drive shaft unlatching tool. A check is made to ensure that the drive shafts are fully disconnected from the RCC. The control rod drive shafts remain with the reactor vessel upper internals.

17. Reactor internals lifting rig is lowered into position over the guide studs by the plant crane. The rig is then secured to the support plate of the upper internals structure.

18. Reactor vessel upper internals and control rod cluster drive shafts are lifted out of the vessel and stored in the underwater storage stand in the refueling cavity.

19. Fuel assemblies and control rod clusters are now free from obstructions and are ready to be removed from the reactor core.

14.4.3 Phase III - Fuel Handling

1. Refueling sequence is started with the refueling machine.

2. Machine is positioned over a fuel assembly in the most depleted region of the core.

3. Fuel assembly is lifted to a predetermined height sufficient to clear the reactor vessel and still have sufficient water covering it to prevent any radiation hazard to the operating personnel.

4. Refueling machine is moved to line up the fuel assembly with the fuel transfer carriage.

5. Fuel transfer carriage is moved into the fuel transfer canal from the fuel building. In one of the containers is a fresh fuel assembly; the second container is empty.

6. Fuel assembly containers are tipped upright by the hydraulically operated lifting arm.

7. Refueling machine loads the spent fuel assembly into the empty fuel assembly container of the carriage and then unloads the fresh fuel assembly and return to the

core.

8. Containers are lowered to the horizontal position by the lifting arm.

9. Carriage is moved through the fuel transfer tube to the fuel building.

10. Fuel assembly containers are tipped upright. A new assembly brought from its storage location is loaded into the empty fuel assembly container.

11. Spent fuel assembly is unloaded by the long-handled tool attached to the fuel handling machine hoist.

12. Fuel assembly container is lowered to the horizontal position, and the conveyor car is moved back into the containment.

13. Meanwhile, the refueling machine has moved another spent fuel assembly with an RCC assembly into the RCC change fixture.

14. Refueling machine takes the fresh fuel assembly, which is to receive an RCC, from the fuel transfer basket and places it in the RCC change fixture.

15. RCC change fixture removes the RCC assembly from the spent fuel.

16. RCC assembly is placed in the fresh fuel assembly.

17. Spent fuel assembly is removed from the RCC change fixture and placed in one of the fuel assembly containers.

18. Fresh fuel assembly with RCC assembly is taken by the refueling machine to the core.

19. Fuel assembly containers are lowered to the horizontal position by the lifting arm.

20. Carriage is moved through the fuel transfer tube to the fuel building to continue the fueling process.

21. Partially spent fuel assemblies are moved from one region to another region of the reactor core.

22. New fuel assemblies are loaded into the proper region of the core.

23. Applicable RCC and thimble plug shuffling is done with the manipulator crane, RCC change fixture, and thimble plug handling tool.

14.4.4 Phase IV - Reactor Reassembly

1. Fuel transfer tube gate valve is closed.

2. Old o-rings are removed from the reactor vessel head, the grooves cleaned,and new ring installed.

3. Reactor vessel upper internals are placed in the vessel by the polar crane. The reactor vessel internals lifting rig is removed and stored.

4. Control rod drive shafts are latched to the rod cluster control assemblies.

5. Reactor vessel head is picked up by the plant crane and positioned over the reactor vessel.

6. Reactor vessel head is slowly lowered. Simultaneously, the water level is kept just below the head.

7. When the head is about 1 foot above the vessel flange, the refueling cavity is completely drained, and the flange surface is cleaned.

8. Reactor vessel head is seated.

9. Reactor vessel head lifting rig tripod is removed, and the cavity is decontaminated.

10. Stud hole plugs and guide studs are removed.

11. Head studs and nuts are installed and torqued.

12. Blind flange is installed to close the containment side of the fuel transfer tube.

13. Vessel head insulation and instrumentation are installed.

14. Missile shield support beams and cable trays are installed.

15. Control rod drive mechanisms are checked out for proper operation.

16. Control rod drive missile shield is installed.

17. Electrical leads and cooling air ducts are installed.

18. Incore instrumentation thimble guides are inserted into the core and sealed at the seal table.

19. Hydrostatic test is performed on the reactor vessel.

14.4.5 Phase V - Preoperational Checks, Tests, and Startup

Preoperational physics tests are performed as necessary.

14.5 New Fuel Handling

New fuel handling involves:

1. Unloading the new fuel shipping containers from the transport vehicle and storing the containers in the fuel building,

2. Removing new fuel from the shipping containers,

3. Inspecting and storing the new fuel, and

4. Maintaining security of the new fuel.

A typical fuel shipment on a flat bed trailer consists of six containers each containing two new fuel assemblies. A piggyback rail shipment would carry two such flat bed trailers. The fuel assemblies are secured to a shock-mounted strong-back, located inside the container, and are shipped in the horizontal position.

The new fuel elevator, located on the side of the spent fuel canal, is used to lower new fuel assemblies down into the canal. Following receipt inspection, a new fuel assembly is placed in the elevator using a short-handled tool suspended from a hoist. The elevator is then lowered into the canal where the spent fuel handling tool is attached, and the new fuel assembly is transferred to a storage cell, where it remains until transferred into the reactor containment.

14.6 Common Refueling Equipment Modifications

The refueling operation contributes significantly to the radiation exposure of plant personnel and to plant downtime. For these reasons, some utilities have elected to add capital equipment to achieve operational advantages. The four most common additions are the improved vessel head closure system, the integrated reactor vessel head package, the quick-opening transfer tube closure, and the SIGMA manipulator crane.

14.6.1 Improved Reactor Vessel Head Closure System

The improved pressure vessel head closure system significantly reduces the time required to tension/detension and remove/insert the vessel studs during the refueling operation.

The system includes:

1. A quick-acting stud tensioning device with a high-capacity hydraulic control cart to speed up the tensioning operation,
2. An improved radial arm hoist to position studs and tensioners radially and circumferentially,
3. A motor-driven stud removal tool, and
4. Stud support collars to permit lifting of the studs with the head.

14.6.2 Integrated Reactor Vessel Head Package

The integrated reactor vessel head package is a system that combines the head lifting rig, seismic platform, lift columns, reactor vessel missile shield, control rod drive mechanism forced-air cooing system, and electrical and instrumentation cable routing into a single, efficient design package. This system eliminates removal and replacement of the control rod drive mechanism cooling system, the control rod drive mechanism missile shield, and the head lifting rig.

14.6.3 Quick-Opening Transfer Tube Closure

The fuel transfer system utilizes a blind flange closure on the reactor containment end of the transfer tube. This flange is attached to the tube by bolts which must be removed and reinstalled for each refueling.

A quick-opening transfer tube closure was developed to reduce both the time needed for this task and radiation exposure. This quick-opening transfer tube closure is flange locked and held in place by toggle mechanisms actuating a series of radial latches. It replaces the old-style blind flange. The assembly is held by a davit for pivoting and raising when the transfer tube is being opened.

14.6.4 SIGMA Manipulator Crane

When thimble plugs and rod cluster control assemblies are changed from one fuel assembly to another with a standard refueling machine, the fuel assemblies are placed in the fuel transfer upender or rod cluster control change fixture to facilitate removal/insertion with a long tool. By providing the capability for the handling of thimble plugs and rod cluster control assemblies in the mast, Westinghouse has eliminated the need for the machine to travel to and from the fuel transfer system upender or the rod cluster control change fixture, the long-handled tool operations, and the need for fuel retrieval.

14.7 Reactor Cavity Filtration System

During refueling, the reactor cavity water often becomes turbid, which makes it difficult to observe the removal and replacement of fuel assemblies. This turbidity is caused by the dislodgement of particles when the cavity is flooded. The reactor cavity filtration system was developed to counteract this problem. The system is effective in clarifying cavity water overnight and maintaining clarity for the duration of the refueling operation.

The reactor cavity filtration system consists basically of a stainless steel pump, its motor, and four stainless steel filter housings.

The pump is a 250 gpm, centrifugal, self-priming stainless steel model with special seals which are resistant to boric acid attack and powered by a 7.5-hp electric motor. The pump and motor are mounted on a common base with the inlet and outlet having flanged connections. The pump and motor unit is easily transportable through the personnel access hatch.

The filter unit consists of four filter housings, valves, and associated piping mounted on a common base. The layout of this assembly is such that each filter housing can be isolated from the system for filter cartridge replacement while the system remains in operation.

14.8 Spent Fuel Pit Cooling System

14.8.1 Introduction

The spent fuel pit cooling system is designed to remove the decay heat generated by the spent fuel elements. The system serves the spent fuel pit, which is shared on a two unit station.

System design considers the possibility that, during the life of the plant, it may become necessary to totally unload a reactor core for maintenance or inspection at a time when one-third of a core from each unit is already in the spent fuel pit. The spent fuel pit cooling system incorporates redundant active components with piping arranged such that failure of any pipe will not drain spent fuel pit water level below the top of the stored fuel elements (Figure 14-6).

The spent fuel pit cooling system consists of two cooling trains, each of which is capable of maintaining the pit temperature at approximately 120°F.

14.8.2 System Design and Operation

Each of the two cooling loops in the spent fuel pit cooling system consists of a pump, heat exchanger, filter, demineralizer, piping and associated valves and instrumentation. Each pump draws water from the pit, circulates it through a heat exchanger, and return it to the pit. The heat exchanger is cooled by the component cooling water system.

The spent fuel pit pump suction lines penetrate the pit wall above the level of the fuel assemblies to prevent uncovering the assemblies as a result of a suction line rupture. If all cooling is lost, the time required for the spent fuel pit temperature to reach 212°F with normal storage (2/3 of a core) is approximately thirty hours.

During normal conditions, 1/3 of a core per unit is stored in the spent fuel pit. With 2/3 of a core present, one pump and heat exchanger can maintain pit temperature less than 120°F. When 1-2/3 cores are stored, one train can maintain temperature less than 150°F. The spent fuel pit is initially filled with borated water at the same concentration as the refueling water storage tank (2000 ppm).

LEGEND:

1. CONTAINMENT
2. FUEL BUILDING
3 REFUELING CAVITY
4 FUEL TRANSFER CANAL
5. OPERATING DECK
6. CONTAINMENT POLAR CRANE
7. REACTOR VESSEL HEAD ASSEMBLY (ON STORAGE STAND)
8. UPPER INTERNALS STRUCTURE (ON STORAGE STAND)
9. LOWER INTERNALS STORAGE STAND
10 REACTOR VESSEL
11. REACTOR CORE
12. REFUELING MACHINE
13. ROD CLUSTER CONTROL CHANGING FIXTURE
14. FUEL TRANSFER TUBE
15. FUEL HANDLING MACHINE AND HOIST
16. FUEL STORAGE TANKS
17. SPENT FUEL CASK LOADING AREA

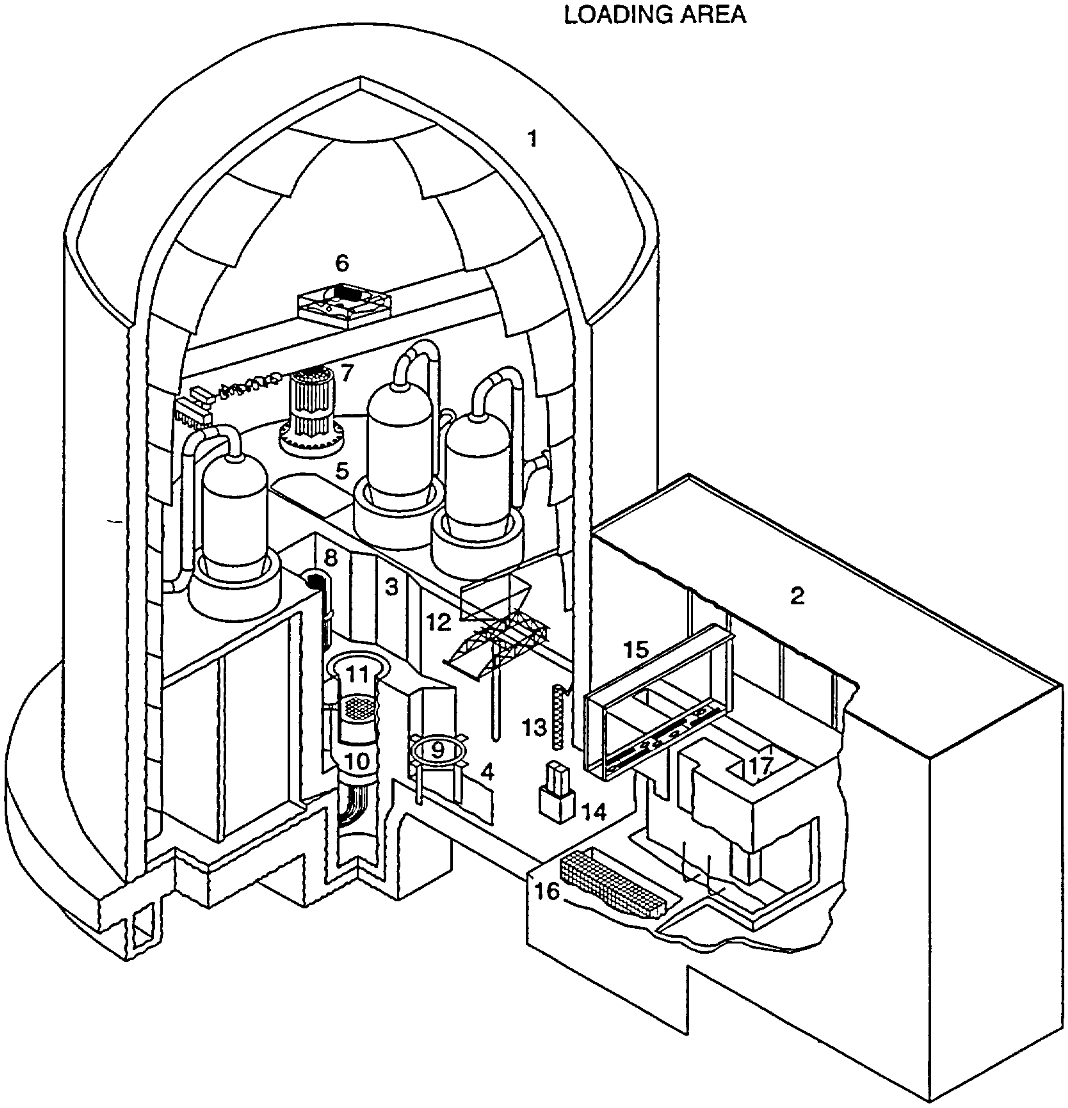

Figure 14-1 Containment Building

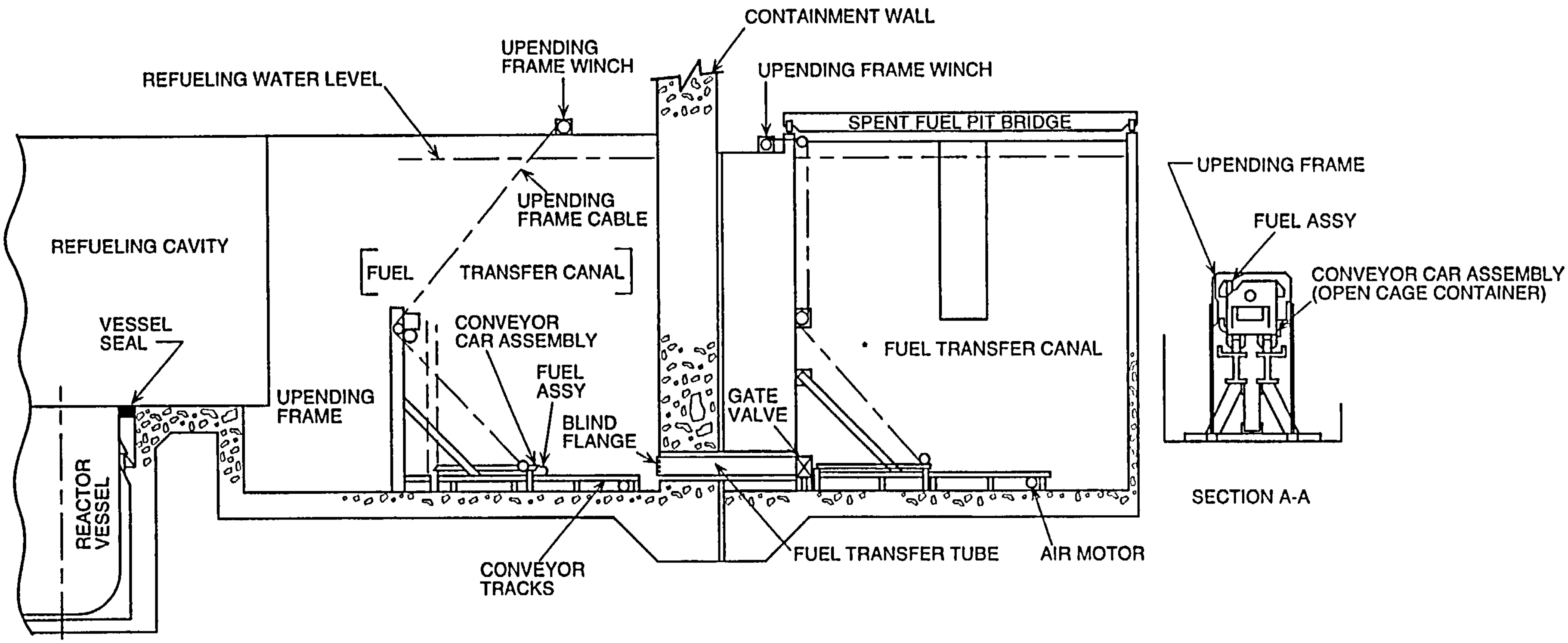

Figure 14-2 Fuel Transfer System

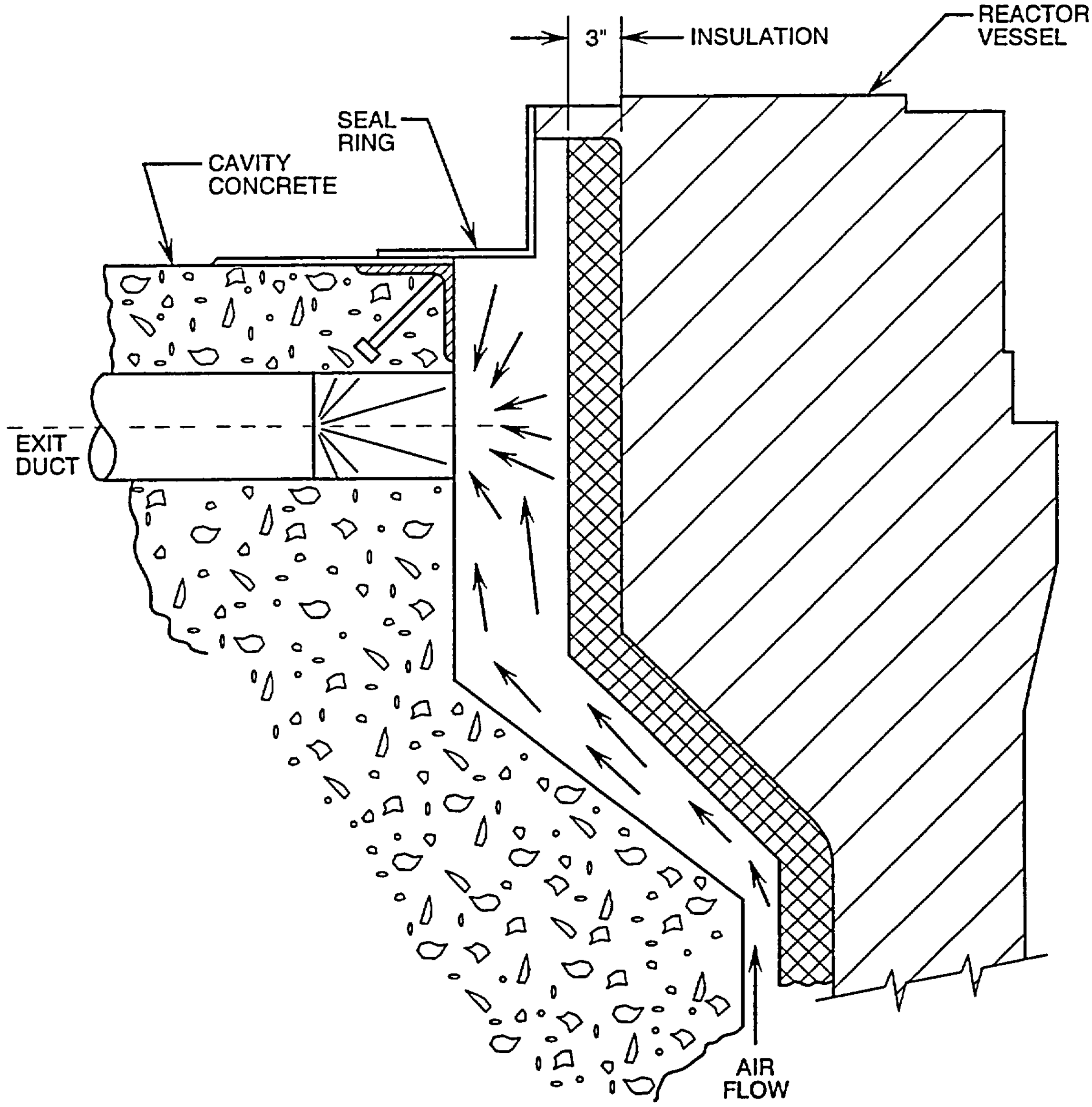

Figure 14-3 Permanent Cavity Seal Ring

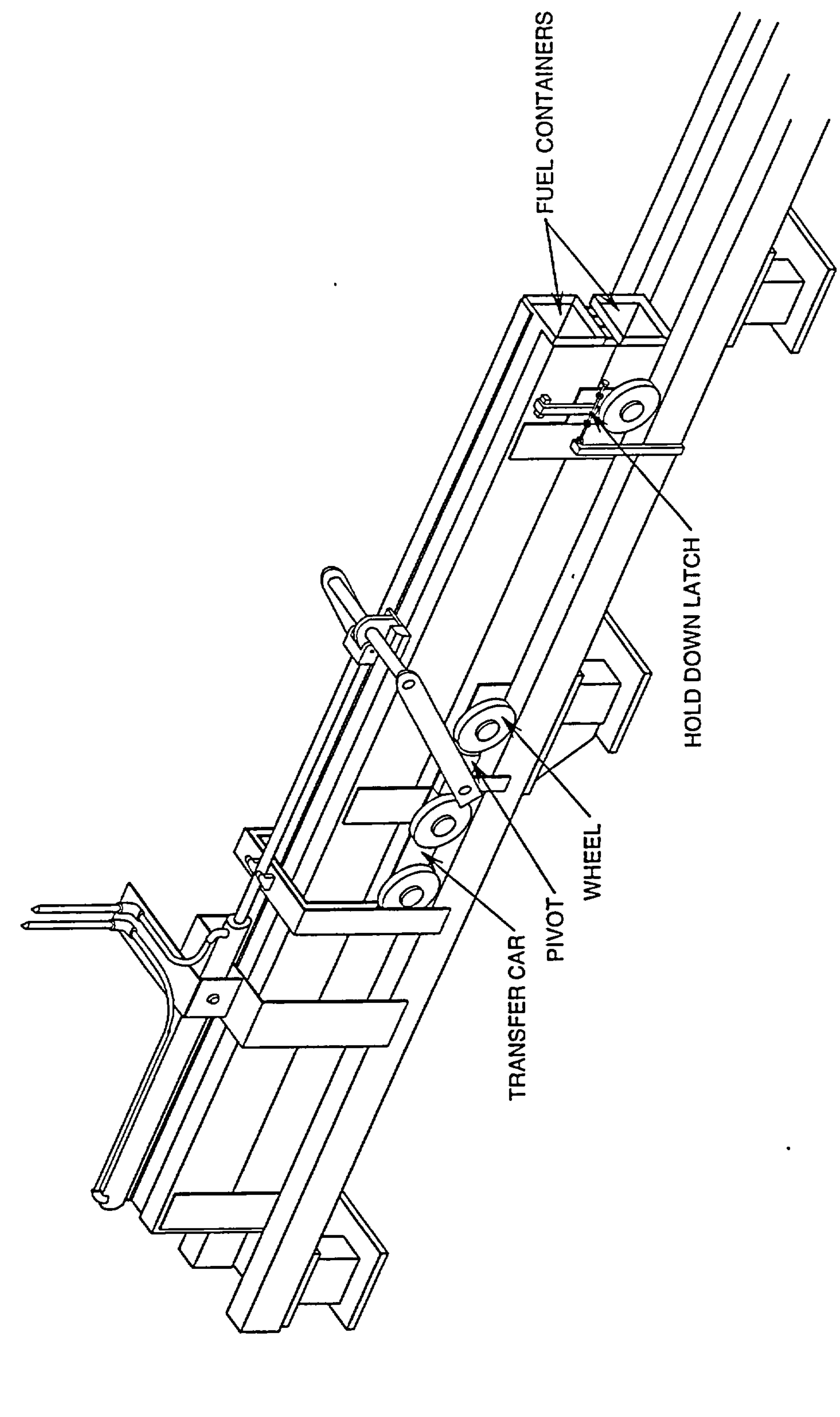

Figure 14-4 Duel Basket Fuel Transfer Car

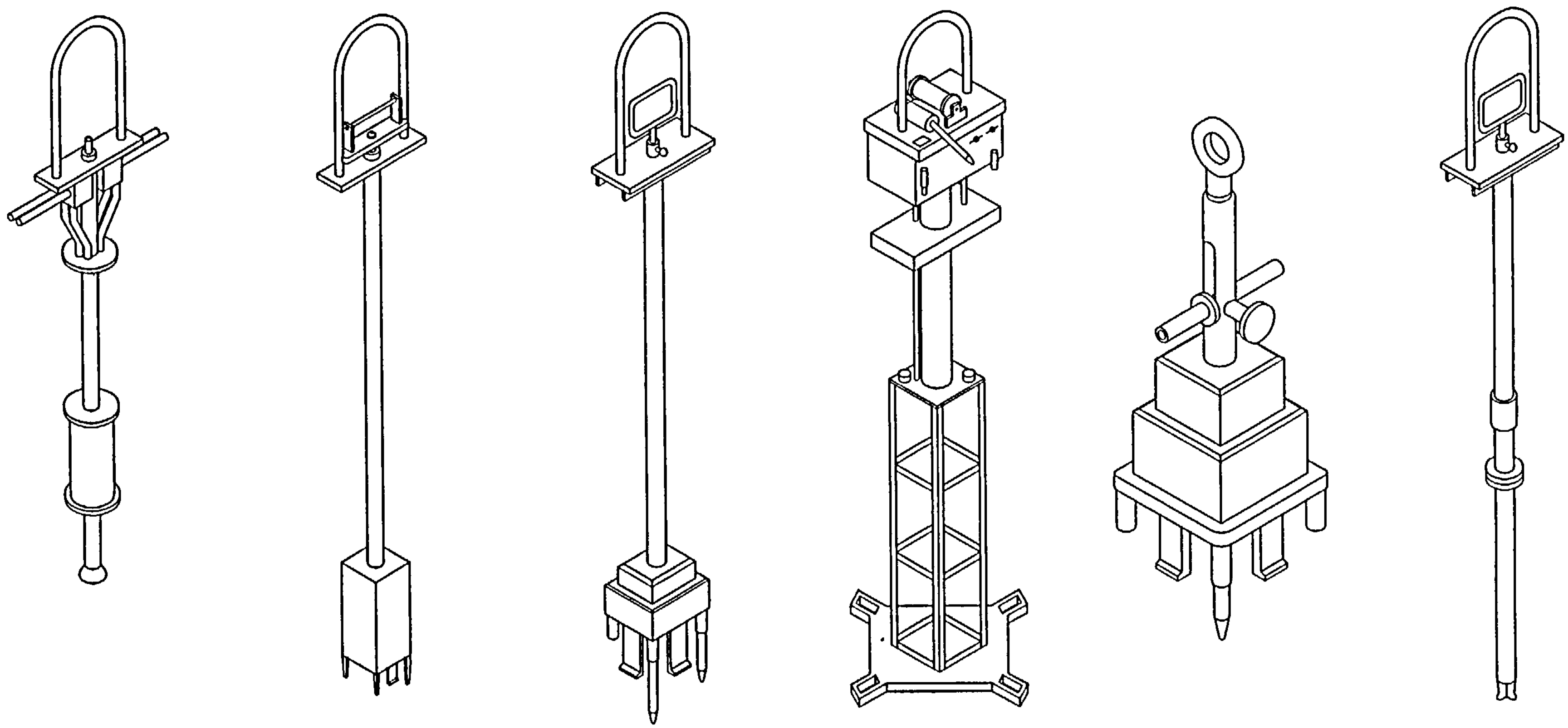

Figure 14-5 Fuel Handling Tools

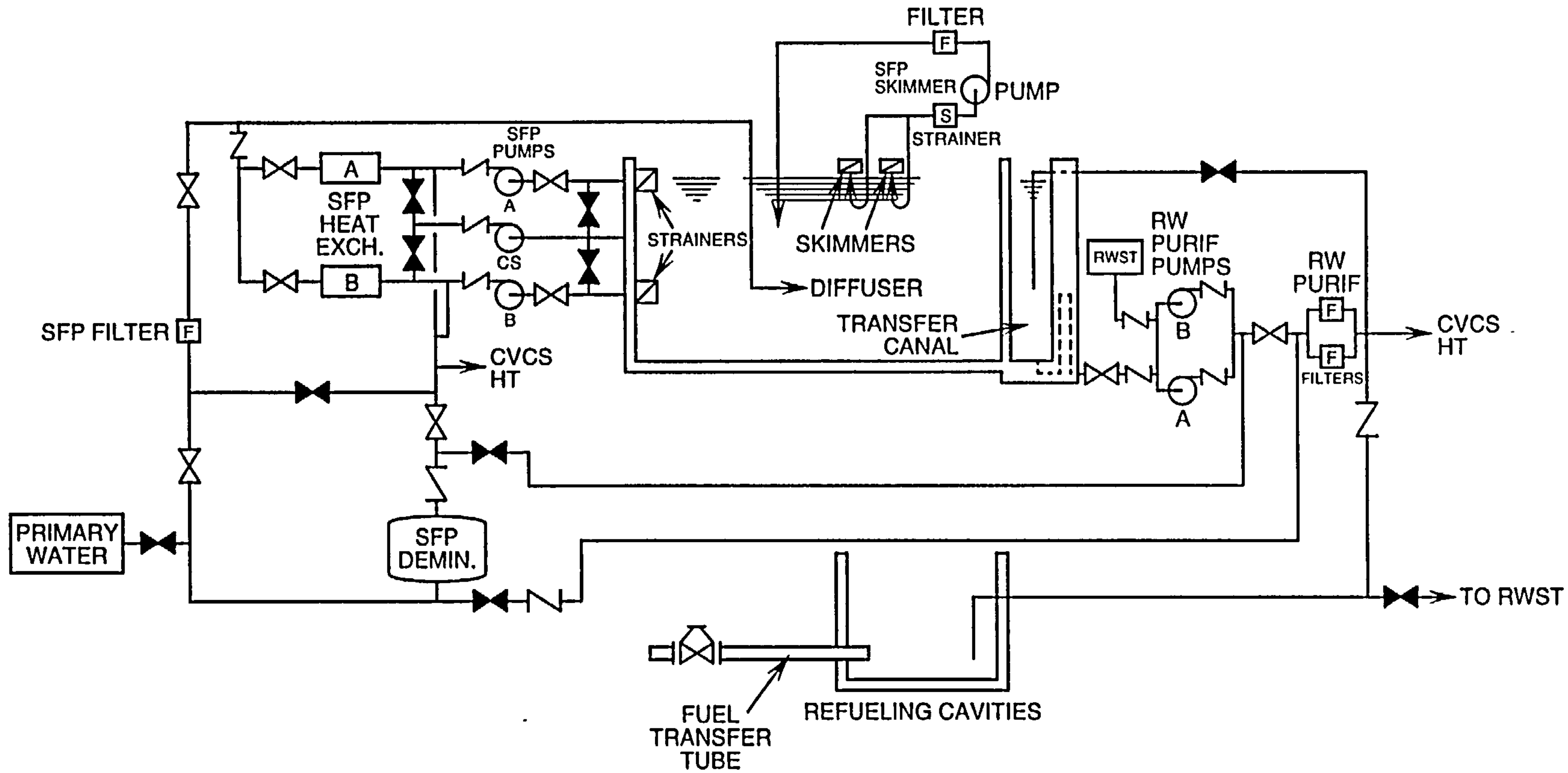

Figure 14-6 Spent Fuel Pit Cooling and Purification System

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Chapter 15.0

Radioactive Waste Disposal Systems

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15.0 RADIOACTIVE WASTE DISPOSAL SYSTEMS

Learning Objectives:

1. State the purpose of each of the following radioactive waste processing systems:

   a. Liquid radioactive waste processing system,
   b. Solid radioactive waste processing system, and
   c. Gaseous radioactive waste processing system

2. Concerning the liquid radioactive waste processing system:

   a. Explain why liquid radioactive waste is separated into reactor grade and non-reactor grade waste,
   b. List two inputs into the reactor grade waste subsystem, and
   c. Describe four methods of processing liquid radioactive wastes.

3. Concerning the solid radioactive waste processing system:

   a. List the two categories of solid radioactive waste, and
   b. List two contributors to solid radioactive waste.

4. Concerning the gaseous radioactive waste processing system:

   a. List the principle volume contributors to the gaseous radioactive waste system, and
   b. List two major radioisotope contributors to the gaseous radioactive waste system.

15.1 Introduction

During operation of a nuclear power plant, radioactive liquids, solids, and gases are formed. This radioactive material must be safely collected and processed so that essentially zero activity is released to the environment.

The liquid waste processing system is designed to collect, process, monitor, and recycle for reuse the liquid waste effluents generated during various plant operations. The waste gas processing system stores waste gases for fission product decay and eventual release. Wastes which cannot be recycled and must be disposed of safely are volume reduced and packaged for disposal by the solid waste systems.

The three separate systems used in this process are discussed individually in the following sections.

15.2 Liquid Waste Processing

The function of the liquid waste processing system is to collect, segregate, and process the reactor-grade liquid wastes during plant operations, refueling, and maintenance. The processed reactor-grade water is recycled for plant use, while non-reactor-grade liquids are processed and disposed of safely. Reactor-grade liquid waste is water that has been passed through the core and contains tritium. The environmental release limits for tritium are very stringent, so the plants recycle this water rather than release it to the environment.

The liquid waste processing system design includes sufficient capacity, redundancy, and flexibility to assure that under any reasonably expected plant condition, any waste water generated will be able to be processed for reuse or release. A system functional block diagram is shown on Figure 15-1.

The system is designed to collect the vent and drain effluents from the reactor coolant system and its associated subsystems. These reactor-grade effluents enter the system from equipment leaks and drains, valve leakoffs, pump seal leakoffs, tank overflows, and other tritiated water sources. The system also collects chemical drains, floor drains, and the waste water from the laundry and shower facilities. Normally, the recyclable liquid (Drain Path A on Figure 15-1) is composed of all tritiated effluents, while the non-recyclable liquid (Drain Path B on Figure 15-1) is composed of non-tritiated or very slightly tritiated effluents. The liquid waste processing system also provides capability for handling and storage or spent ion-exchange resins.

Deaerated, tritiated liquid inside the containment may enter Drain Path A through connections to the reactor coolant drain tank. Connections are provided for various drains and leakoffs, and for cooling the pressurizer relief tank. This deaerated, tritiated liquid is normally sent directly to the recycle holdup tanks from the reactor coolant drain tank for reuse rather than being processed by the liquid waste processing system. If chemical analyses indicated that this liquid required processing, it would be transferred from the recycle holdup tanks to the waste holdup tanks.

Aerated tritiated liquid enters the recyclable waste system portion of Drain Path A through lines connected to the waste holdup tank. Sources of this aerated liquid are as follows:

a. Sample room sink drains,
b. Ion exchanger, filter, pump, and other equipment drains, and
c. Refueling canal drains.

The aerated drainage collected is pumped to the waste holdup tank for processing. Therefore, the waste holdup tank is the initial collecting point for aerated, recyclable liquids which must be processed through the waste evaporator prior to reuse.

The waste evaporator feed pump delivers the contents of the waste holdup tank through a filter to the waste evaporator for processing prior to reuse. The noncondensible gases are released to the plant vent, and the distillate is directed through a demineralizer filter to the waste evaporator condensate tank. The evaporator bottoms are normally placed in steel drums for storage or disposal. Concentrates (in the form of boric acid) may also be recycled if found acceptable by analysis.

Drain Path B collects effluents from the primary plant which are normally not recycled. These effluents are generally segregated according to their chemical makeup and may be drummed or processed through the waste evaporator and demineralizer.

Drain Path B is comprised of three drain paths, each associated with one of the following:

a. Laundry and hot shower tank,
b. Floor drain tank, or
c. Chemical drain tank.

Laundry and detergent wastes flow to the laundry and hot shower tank. Nondetergent wastes flow into the floor drain tank. Laboratory samples which contain reagent chemicals (and possible tritiated liquid) are drummed directly after being discarded through a separate sample room sink which drains to the chemical drain tank. (Reactor coolant excess samples are directed to the waste holdup tank.) Rinse water from the laboratory is discarded to the floor drain tank because of its relatively large volume and low impurity content.

A radiation monitor is located in the discharge line from the waste monitor tanks. This monitor controls the air-operated discharge valve in the line and closes it automatically if the activity level in the discharge stream exceeds a pre-set level. The liquid is first sampled and analyzed before discharge so,therefore, the operation of this valve should be very infrequent.

Water is accumulated in the waste holdup tank until sufficient quantity exists to warrant an evaporator startup or to switch the evaporator operation from the floor drain tank to the waste holdup tank. For example, if 3,000 gallons exists in the waste holdup tank, a 15 gpm evaporator can process it in about 3.5 hours. The evaporator distillate is normally passed through the waste evaporator condensate demineralizer before being transferred to the waste condensate tank. If re-evaporation is required and the waste evaporator is not available, then the contents of the waste condensate tank can be transferred to the recycle holdup tanks for processing by the recycle evaporators. The bottoms from the waste evaporator should be concentrated to approximately 12 percent boric acid and should normally be drummed. If a situation occurs such that the bottoms can be recycled, they should be transferred to the boric acid tanks.

15.2.1 Waste Disposable Subsystem Operation

The disposable waste portion of the liquid waste processing system consists of three parts:

a. Laundry and hot shower system,
b. Floor drain tank system, and
c. Chemical drain system.

Laundry and hot shower drains enter the laundry and hot shower tank for holdup. The normal mode of operation is to transfer this water directly to the waste monitor tank for sampling and discharge. The water in the floor drain tank is sampled to determine the degree of processing required. It can be sent directly to the waste monitor tank provided for floor drain tank water; to the waste monitor tank via the waste monitor tank demineralizer; or it can be processed through the waste evaporator. If the floor drains are evaporated, the condensate is sent to the waste monitor tank, and the concentrate is drummed. The water in the waste monitor tank is again sampled and can be recirculated through the waste monitor tank demineralizer if further processing is required. When this water has been sufficiently processed, it is discharged into the condenser cooling water at a rate determined by the dilution flow rate available.

The containment sump is normally drained to the floor drain tank. However, if sampling indicates high quality water in the sump, it can be routed to the waste holdup tank for recycle. During refueling operations, the load on the waste portion of the liquid waste processing system is increased, but the process is the same.

15.2.2 Chemical Drain Subsystem

The chemical drain system consists of one sink in the laboratory and the chemical drain tank and pump. Spent reactor coolant samples which are handled in the laboratory are disposed of via the chemical drain tank sink. When sufficient waste is collected in the tank, it is drummed.

Equipment rinse water and other non-reactor grade water is disposed of via the floor drain tank sink. This water is processed as described above.

15.3 Solid Waste Processing

The solid waste processing systems include the radwaste volume reduction/solidification system and the radwaste incineration system. The systems reduce in volume and solidify low level radioactive plant wastes and prepare them for safe storage and/or disposal.

Solid radwaste is categorized into wet waste and dry waste. Wet waste includes spent resins, evaporator bottoms, wet rags, etc. Dry waste includes contaminated tools, used anti-contamination clothing, and contaminated equipment parts.

The radwaste volume reduction/solidification system employs a vacuum cooled crystallization process to effect volume reduction, coupled with high speed, high shear mixing of the wet waste with cement to achieve solidification. For combustible plant wastes, the radwaste incinerator utilizes a controlled air incineration process.

Volume reduction of concentrated evaporator bottoms, which may include boric acid wastes, laundry wastes, chemical wastes, and other floor drain wastes, is accomplished in the radwaste volume reduction system (Figure 15-2). The major components of the system are the crystallizer chamber and recirculation system, condenser, and vacuum pump system. The crystallizer chamber consists of a conical tank and an inner circular baffle to separate solid crystals from a clear recycle stream.

Solidification of the volume-reduced wastes and other low-level radioactive wastes, such as spent resins and contaminated tools, is performed in the cement solidification system (Figure 15-3). The major components of the cement solidification system include the high shear radwaste mixer, waste dispensing system, flush water recycle steam, cement storage and feed system, and the container handling system.

15.4 Gaseous Waste Processing

The waste gas system removes noncondensible gases (primarily N_2 and H_2) and fission gases (primarily Xe-133 and Kr-85) from contaminated fluids and contains them indefinitely to eliminate the need for regularly scheduled discharges of radioactive gases from the system into the atmosphere during normal plant operation.

Since the system also provides for reducing the concentration of fission gases in the reactor coolant to a low residual level, it functions to reduce the escape of radioactive gases during maintenance operations or through unavoidable equipment leaks. Design is based on continuous operation of the nuclear steam supply system assuming 1% fuel cladding defects. This condition is assumed to exist over the full life of the plant.

Although the system is designed to eliminate regular atmospheric discharge of waste gases, it is acknowledged that disposal of radioactive gas may become necessary at some time during the plant life. Therefore, the system includes provisions to sample and isolate each of the gas decay tanks, and a means of removing radioactive gases from the site. First, low activity gases that might accumulate from operations such as plant shutdown or pressurizer relief tank discharges can be disposed of by discharge from a shutdown tank to the atmosphere after decay. Controls are provided to make certain that these releases are made within the established Technical Specification limits.

Second, high activity gases that might have to be removed from the normal process loop can be disposed of by discharge into gas bottles or tanks. These containers can be stored on-site until disposal for burial or processing off-site.

As shown on the schematic flow diagram (Figure 15-4), the waste gas processing system is a closed loop comprised of two waste gas compressors, two catalytic hydrogen recombiners, four to eight gas decay tanks (depending upon the plant size and site location) for normal power service, and two gas decay tanks for service at shutdown and startup. All of the equipment is located in the auxiliary building. The standard system is designed to service both single and twin unit stations with two, three, or four loop plants.

During normal power operation, nitrogen gas is continuously circulated around the waste gas system loop by one of the two compressors. Fresh hydrogen gas is charged to the volume control tank, where it is mixed with fission gases which are stripped from the reactor coolant. The contaminated hydrogen gas is vented from the volume control tank into the circulating nitrogen stream in the waste gas loop. The resulting mixture of nitrogen, hydrogen, and fission gases (xenon and krypton) is pumped by one of the two compressors to a catalytic hydrogen recombiner where enough oxygen is added to reduce the hydrogen to a low residual level. After water vapor, formed in the recombiner, is condensed and removed, the cooled gas stream is discharged through a gas decay tank and sent back to the compressor suction to complete the loop. When the radiation level in one gas decay tank reaches a predetermined limit, that tank is valved out of service, and another tank is valved in. At any given time, fission gases contained in the gas decay tanks will be separated into several discreet parts, each in a different stage of decay.

When the residual fission gases and the hydrogen contained in the reactor coolant must be removed in preparation for a cold shutdown, operation of the waste gas system remains unchanged until after the reactor is shut down and the coolant fission gas concentration is reduced to the desired level. At that time, the operator stops the volume control tank purge flow from the unit still at power if the plant is a twin unit station, and starts a nitrogen purge in the unit which is shutdown. The gas decay tank which was in service during power generation is valved out of operation, and one of the two shutdown/startup tanks is valved in. This tank, however, is placed in the process loop directly at the compressor discharge so the gas mixture from the volume control tank is vented to the compressor suction, sent through the shutdown decay tank to the recombiner where hydrogen is removed, and then returned to the compressor suction.

During the first plant cold shutdown, fresh nitrogen is charged to the volume control tank to strip hydrogen from the reactor coolant. The resulting accumulation of nitrogen in the shutdown tank is accommodated by allowing the tank pressure to increase. During subsequent shutdowns, there is no additional accumulation since the nitrogen from the first shutdown will be reused.

Although the system is designed to accommodate continuous operation without atmospheric releases, facilities are provided for controlled discharge of gas from the system against the contingency that an abnormal situation may necessitate such action. Before a tank is emptied to the atmosphere, a gas sample must be analyzed to determine and record the activity to be removed. After sampling, the tank is isolated until its contents are discharged. A trip valve in the discharge line will close automatically if a high activity level in the plant vent effluent is detected.

15.5 Summary

The radioactive waste disposal systems are designed to collect, segregate, process, and monitor plant waste to ensure essentially zero radioactivity is released to the environment. The radioactive waste disposal systems include the liquid waste processing system, the solid waste processing system, and the gaseous waste processing system.

Liquid radwaste is separated into reactor grade and non-reactor grade depending upon the concentration of tritium in the water. Liquid radwaste can be recycled, filtered, demineralized, evaporated, and/or released to the environment when environmental discharge limits are met.

Solid radwaste is separated into wet and dry categories. Wet solid radwaste can be volume reduced and processed through filters, demineralizers, evaporators, and/or the solidification system. Dry solid radwaste is solidified in cement in a drum or other container for storage or disposal.

Gaseous radwaste consists of two major volume contributors, non-condensible nitrogen and hydrogen gas, and two principle radioisotope contributors, namely xenon and krypton. The system is designed to contain and store all waste gas generated for the life of the plant. However, many plants do make gaseous releases to the environment. Catalytic hydrogen recombiners are used to remove the hydrogen from the flow stream. The radioactive gases are allowed to decay to a low activity level before a release to the environment is commenced.

Before a liquid or gaseous release to the environment is commenced, the system is sampled and analyzed to ensure release limits are met prior to initiation of the release. Both the liquid radwaste and gaseous radwaste environmental release paths are designed with an automatic isolation valve which will terminate the release when a high radioactivity level is sensed.

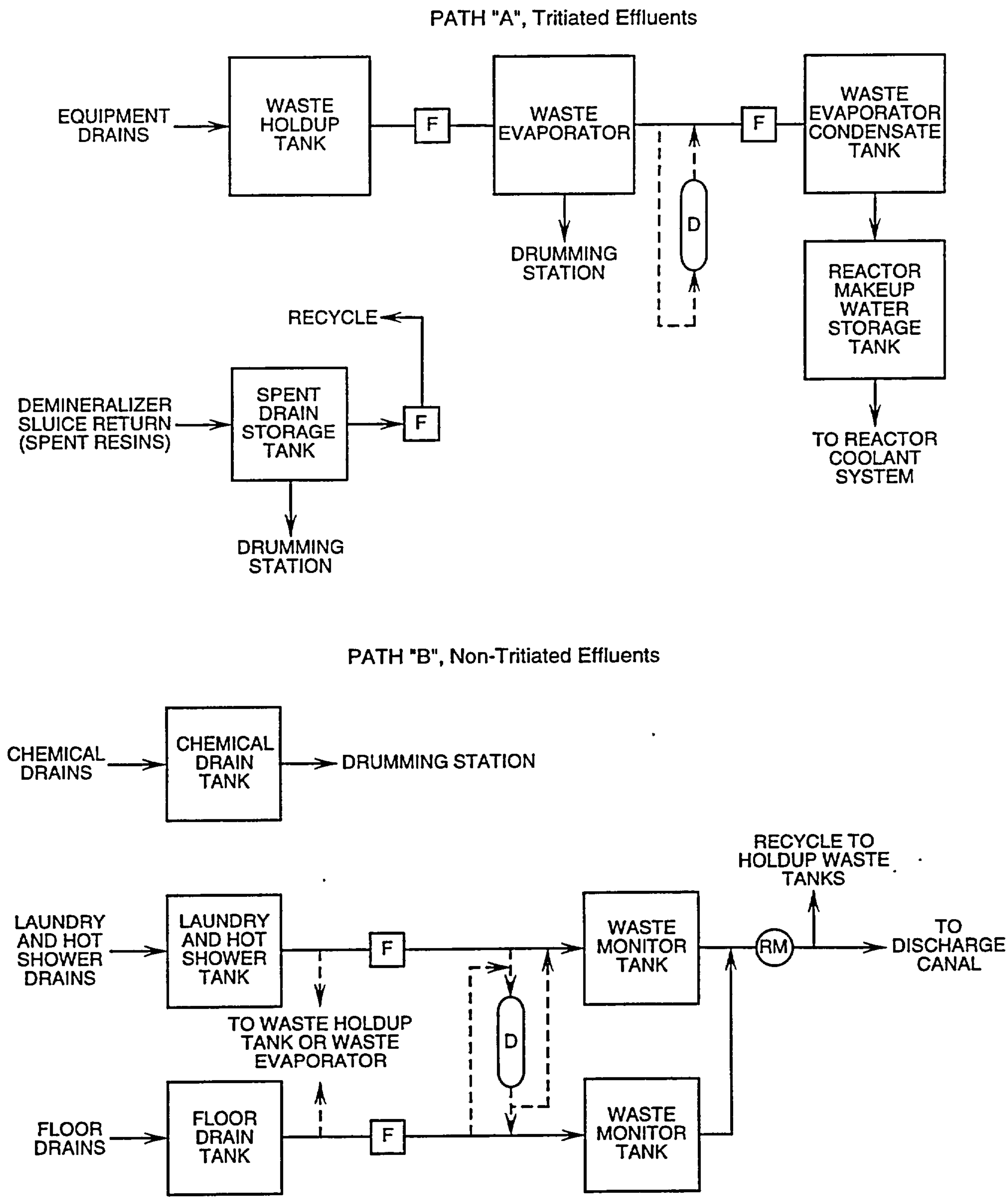

Figure 15-1 Liquid Waste Processing System

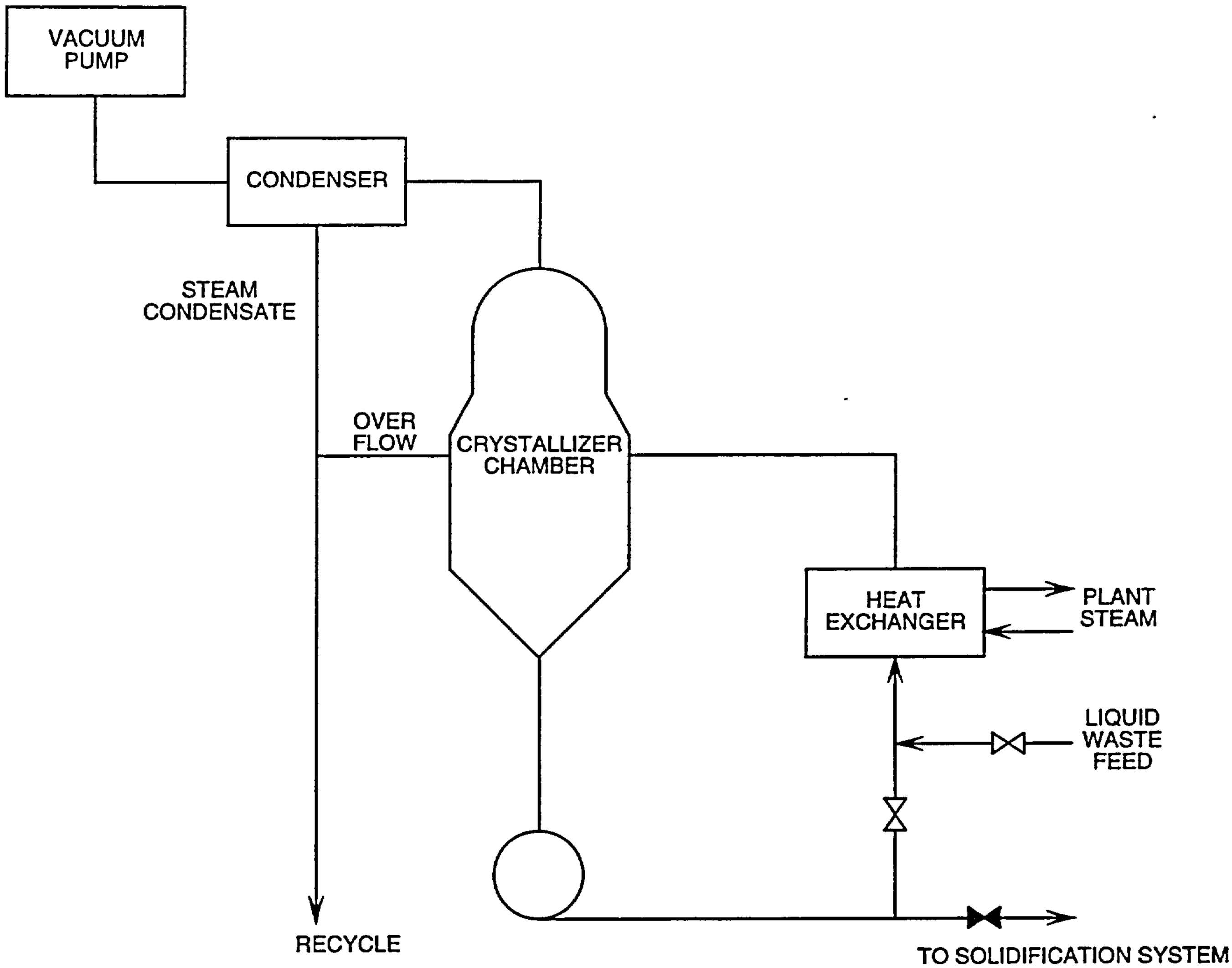

Figure 15-2 Radwaste Volume Reduction System

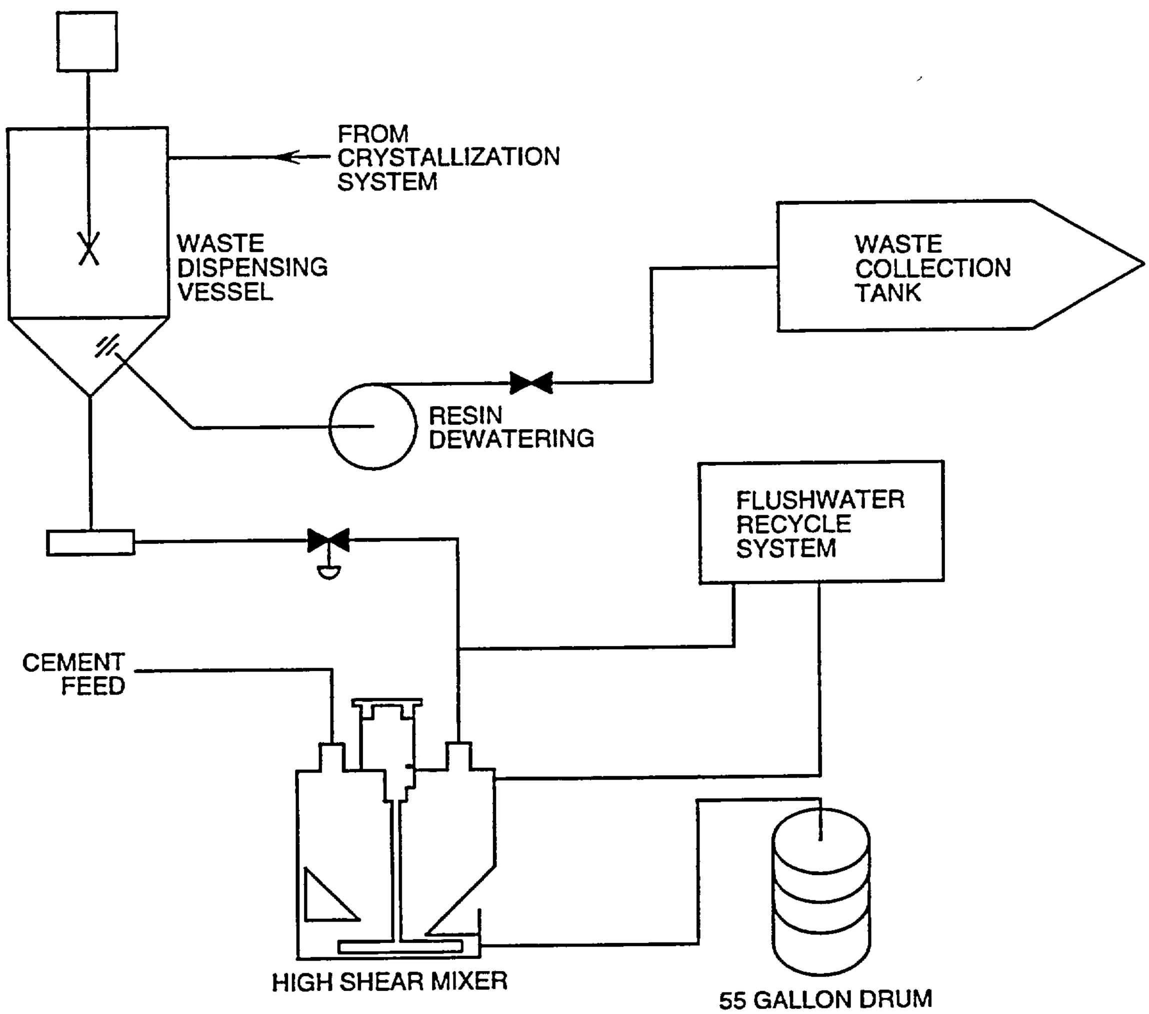

Figure 15-3 Cement Solidification System

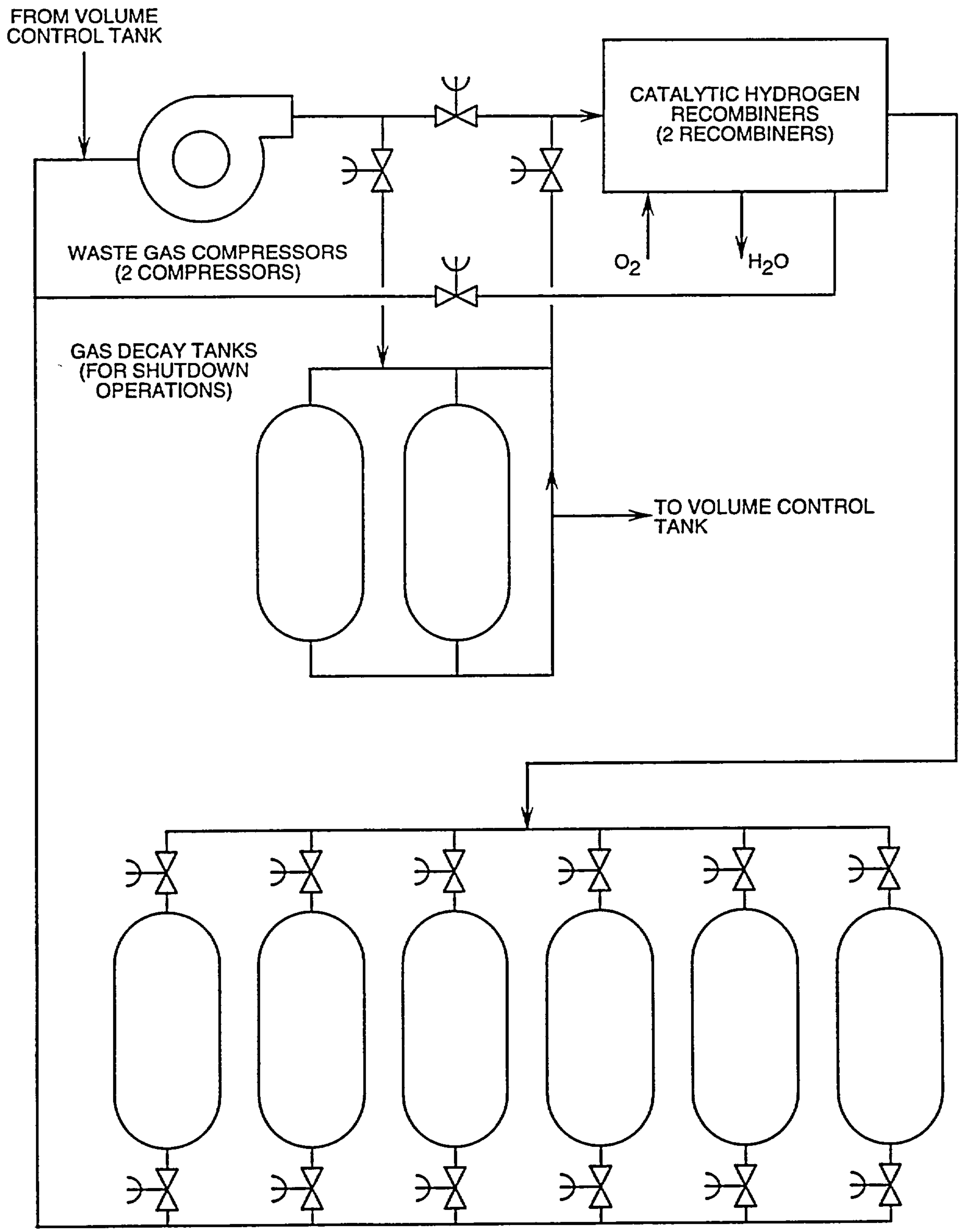

Figure 15-4 Waste Gas System

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Chapter 16.0

Radiation Monitoring System

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16.0 RADIATION MONITORING SYSTEM

Learning Objectives:

1. List three functions of the radiation monitoring system.

2. List the two subsystems of the radiation monitoring system.

3. State the purpose of the area radiation monitoring system.

4. State the functions of the following components used in the area radiation monitoring system:

   a. Detectors,
   b. Electronics channel, and
   c. Remote indicator.

5. State the function of the liquid process monitoring system.

6. State the function of the liquid effluent monitoring system.

7. State the function of the airborne process monitoring system.

8. State the function of the airborne effluent monitoring system.

16.1 Introduction

The functions of the radiation monitoring system are:

1. The area radiation monitors warn of any radiation hazard which might develop within the plant.

2. The process radiation monitors give early warning of a plant malfunction which might lead to a radiation hazard.

3. The effluent process radiation monitors provide a warning of any pending or inadvertent release of radioactivity to the environment.

The radiation monitoring system consists of detection instruments located at selected points throughout the plant to detect, compute, and record radiation levels. If the radiation levels should rise above the setpoint, an alarm is initiated in the control room. The radiation monitoring system is used in conjunction with radiation surveys and chemical and radio-chemical analysis to provide adequate information and warning for safe operation of the plant and to assure that personnel exposure does not exceed the 10CFR20 limits.

The radiation monitoring system is divided into two subsystems:

1. The area radiation monitoring system, which monitors the general area radiation levels at several points throughout the plant to warn the operator of high or abnormal radiation levels. Refer to Table 1.

2. The process radiation monitoring system, which monitors various fluid systems and effluent streams for increasing radiation levels. Refer to Table 2.

16.2 Area Monitoring System

The purpose of the area monitoring system is to monitor area radiation in particular portions of the plant and to alarm if limits are exceeded.

The information from the area monitoring system is displayed on a five decade logarithmic scale meter, which reads out in dose rate, and is located at a centrally placed control chassis in the main control room. This information is also supplied to the plant computer for a CRT display which shows the reading on all channels of the system. A local meter in the vicinity of the detector also reads out in dose rate.

Two channels are used to monitor the radiation levels inside containment following an accident involving a large release of radioactivity. Each channel consists of a detector assembly located adjacent to containment, a remote indicator, and an electronics package. The differences between these two channels and the rest of the area monitoring system are due to the intent of detecting radiation at a higher intensity. The detectors are ion chambers rather than Geiger-Mueller tubes and have a range of 1 to 10^3 R/hr.

The typical area monitor contains a detector assembly, a rack unit, an electronics channel, and a remote indicator. The detector assembly uses a Geiger-Mueller tube (Figure 16-1) is a gas filled chamber which monitors radiation levels by detecting current pulses generated by ionization of the gas caused by interaction with an incident particle. Geiger-Mueller tubes indicate gross radioactivity and can not differentiate between radioisotopes.

If it is desired to monitor for a particular isotope, then a scintillation detector (Figure 16-2) would be used. A scintillation detector contains a window, a crystal, and photomultiplier tube. This type of detector works on the principle that when a radioactive particle interacts with certain materials (crystal), light is produced. The photons (light) are multiplied and produce output pulses which are proportional to the energy of the incident particle. Scintillation detectors can accurately measure alpha, beta, or gamma radiation by using a different crystal material for each type of radiation.

The detector assembly also contains a check source which is operated remotely by pushing the "normal" light on the front of its electronics channel. The signal from the detector is amplified and processed by the line driver. It then is carried via cable back to its electronics channel where it is processed further and read out as dose rate. The sensitivity of the detector is from 0.1 to 10^4 mR/hr.

Rack Unit

The rack unit provides space for approximately six electronics channels and connecting terminals for all the interconnections between the assemblies or to auxiliary components. It also supplies AC power to the electronics channels.

Electronics Channel

The electronics channel receives the signal from the detector assembly, processes the signal, and displays the information in dose rate on the meter mounted on the front of the channel. Each channel contains its own low voltage power supply, electronics for signal processing, readout and alarm display. The readout meter, three alarm lights, and resets are on the front panel. A source check can be actuated by pushing the "normal" light.

Remote Indicator

The remote indicator (Figure 16-3) is a wall mounted unit which displays the meter reading and high alarm condition of the channel to which it is connected. It also provides an audible alarm which can be silenced by pressing the alarm acknowledge push button switch located at the remote indicator.

The remote indicator provides dose rate readings on a five decade logarithmic meter scale. The electronics channel in the rack unit provides the analog meter signal and high alarm actuation signal to the remote indicator. It also provides 12 volt power for the high alarm flashing unit. All connections from the electronics channel pass through the detector assembly, which acts as a junction box.

16.3 Process Monitoring System

The process monitoring system monitors, records, and controls the release of radioactive materials that may be generated during normal operation, anticipated operational occurrences, and postulated accidents.

The system consists of liquid and airborne radioactivity monitors with the attendant controls, alarms, pumps, valves, and indicators required to meet the system's design basis. Each monitor consists of a detector assembly and a local microprocessor. The local microprocessor processes the detector's signal in digital form, computes average radioactivity levels, stores data, performs alarm or control functions, and transmits the digital signal to a control room microprocessor.

The local microprocessor associated with monitors performing safety functions (control room ventilation, containment atmosphere, and containment purge monitors) are wired directly to individual indicators located on seismic category I radioactivity monitoring system cabinets in the control room.

Each monitor is provided with a three level alarm system. One alarm setpoint is below background counting rate and serves as a circuit failure alarm. The other two alarm setpoints provide sequential alarms on increasing radioactivity levels. A loss of power will cause an alarm on all three alarm circuits. The alarms must be manually reset and can be reset only after the alarm condition is corrected. Each monitor is provided with a check source, operated from the control room, which stimulates a radioactive sample in the detector assembly for operational and cross calibration checks.

The control room microprocessor provides controls and indications for the process radioactivity monitoring system.

Indication is via a CRT located in the control room. The signals for each monitor may also be recorded on a system printer.

The process monitoring system is comprised of a number of different types of monitoring devices (Figure 15-4). Basically, monitors will be either the type to monitor liquid activity or airborne activity. Both types can be further divided into process monitors, measuring radioactivity in internal systems, and effluent monitors, which measure radioactivity at the point of release from a system.

Liquid Monitors

The liquid monitors consist of fixed-volume lead shielded sample chamber through which liquid samples flow. A gamma scintillation detector or Geiger-Mueller tube is located within each sample chamber to detect activity level.

Liquid monitor alarms are annunciated in the control room on the plant annunciator, the balance of plant computer, and the radiation monitoring system CRT. The balance of plant computer provides an audible alarm and a visual display on the control room CRT and a printout in the computer room. Monitors are located to provide a representative sample, reduce sample transport time, and limit the amount of radioactivity released in the event of a high activity signal. The control functions are usually only to isolate the effluent stream once the control limit is reached. These isolation functions are designed to prevent release of radioactive liquids to the environment.

Airborne Monitors

The airborne activity monitors extract samples from various process streams and transports the samples to the individual monitoring units which contain equipment to detect particulates, iodine, and gaseous activity.

The detectors are usually scintillation detectors with slight differences, depending upon what isotopes they are intended to detect. All airborne radiation monitors include provisions for obtaining a gas sample for laboratory analysis. Each airborne particulate monitor consists of a fixed filter upon which radioactive particulate matter is deposited. The fixed filter is located in front of a scintillation detector coupled to a photomultiplier tube. Each airborne iodine monitor contains a charcoal cartridge upon which iodine is absorbed. The charcoal cartridge is located in front of a gamma scintillation detector coupled to a photomultiplier tube. The gas sampler consists of a sample chamber (with a prefilter to remove particulates) with a scintillation detector located in the gas chamber. Monitors may contain one, two, or a variety of detection assemblies depending upon their application.

As with the liquid monitors, the airborne monitors also provide alarms and control functions.

16.4 Summary

The area monitoring portion of the radiation monitoring system consists of detectors with their associated electronics, controls, and a remote indicator. The detector sends a signal proportional to the area radiation level to the rack unit assemblies located in the control room. These assemblies hold the electronics channels for each detector. The detector signal drives the meter on the front of the channel and its alarms. This signal from the electronics channel also drives the meter and alarm on the remote indicator. Finally, this signal goes to the plant computer for recording the CRT display. Two additional channels of the area monitoring system are referred to as the post accident monitors. The differ from the rest of the system in that they are designed to detect radiation levels of a much higher range.

The process monitoring system is comprised of various channels which monitor both liquid and airborne process and effluent systems. Each channel has a monitor assembly comprised of the necessary piping, valves, pumping systems, and detectors. Detectors provide information for indicating and recording radioactivity levels. Some channels provide automatic functions and alarms to either protect personnel from exposure or to prevent discharge of excessive radioactivity to the environment.

Table 16-1
Area Radiation Monitors

Location	Detector Type	Automatic Action
1. Main Control Room	G-M tube	Alarm function only*
2. Containment a. Operating deck b. Seal table area c. Dome monitor	 G-M tube or gamma scint. G-M tube Ion chamber	Alarm function only
3. Radio Chemistry Lab	G-M tube	Alarm function only
4. Charging Pump Room	G-M tube	Alarm function only
5. Drumming Station	G-M tube or gamma scint.	Alarm function only
6. Sampling Room	G-M tube	Alarm function only
7. Spent Fuel Building	G-M tube or gamma scint.	Isolates auxiliary building exhaust to gas treatment system.
8. Dry Active Waste Storage Area	Air particulate beta scint.	Alarm function only
9. Gas Decay Tank Rooms	Air sample beta scint.	Alarm function only
10. Radwaste Evaporator Room	Air sample beta scint.	Alarm function only

*Some facilities may provide an automatic isolation of the normal control room ventilation system.

Table 16-2
Process Radiation Monitors

Location	Detector Type	Automatic Action
a. Containment Air Particulate Detector	Gamma scint.	Isolates containment purge and exhaust if running. Isolates relief and vacuum lines. Shifts containment coolers to accident mode.
b. Containment Noble Gas Monitor	Beta scint.	Same as above
c. Purge Exhaust Monitor	APD, G-M tube, gamma scint.	Isolate containment purge supply and exhaust valves if running.
d. Auxiliary Building Ventilation Monitor	Beta scint. Gamma scint.	Initiates auxiliary building isolation. Diverts to gas treatment system.
e. Plant Vent Stack Monitor	G-M tube	Alarm function only.
f. Main Control Room Intake Air Particulate Monitor	Beta scint. Gamma scint.	Isolates main control room ventilation.
g. Condenser Air Ejector Gas Monitor	G-M tube	Alarm function only.
h. Steam Generator Blowdown Liquid Sample	Gamma scint.	Alarm function only.
i. CCW-Downstream of Heat Exchanger	Gamma scint.	Closes CCW surge tank vent
j. Service Water Effluent Discharge	Gamma scint.	Alarm function only
k. Waste Disposal System Liquid Discharge to the Environment	Gamma scint. or G-M tube	Closes the effluent discharge to the environment
l. Gas Decay Tank Effluent Discharge Monitor	Beta scint. or G-M tube	Closes the effluent discharge to the environment

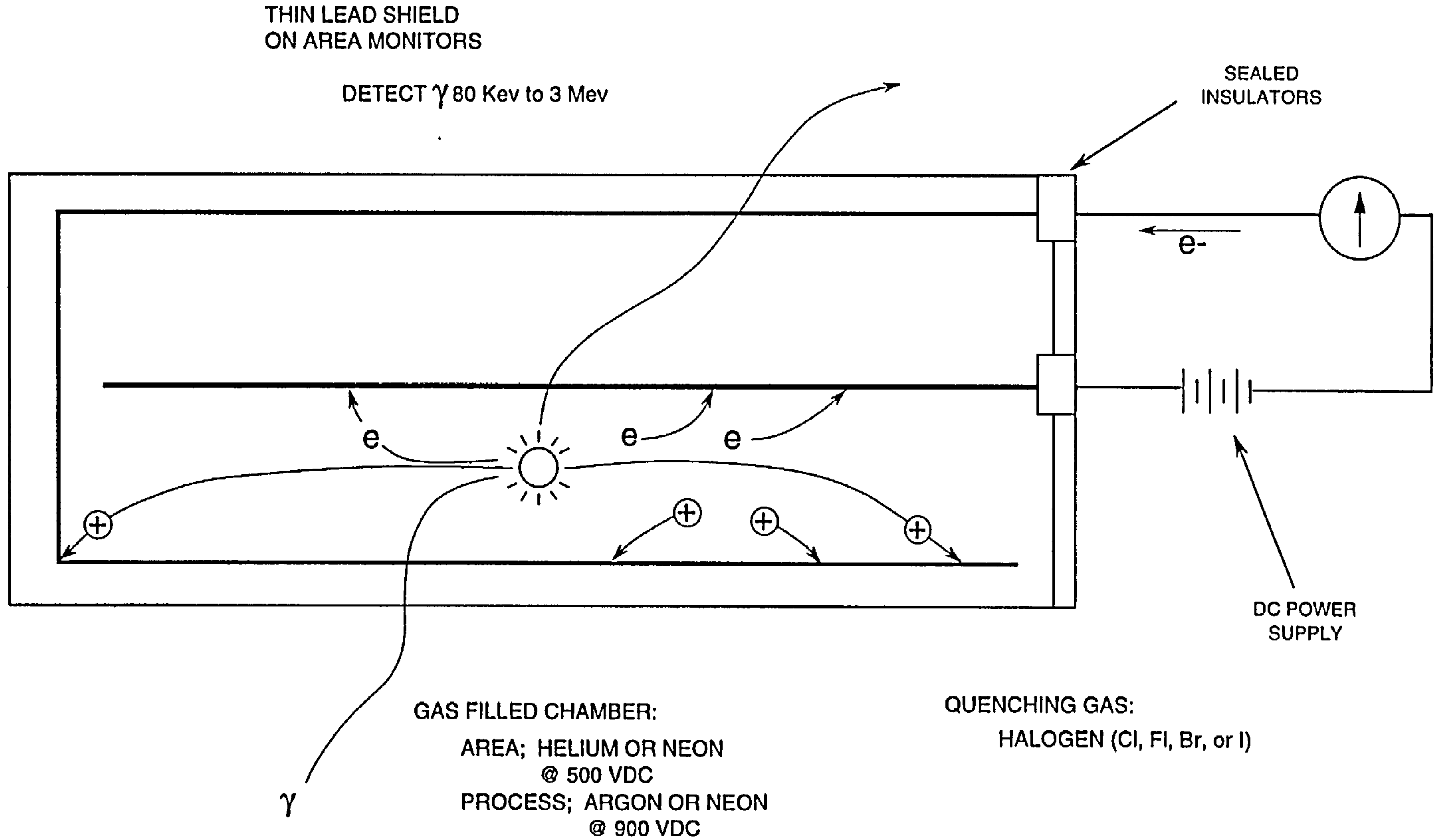

Figure 16-1 Geiger - Mueller Tube

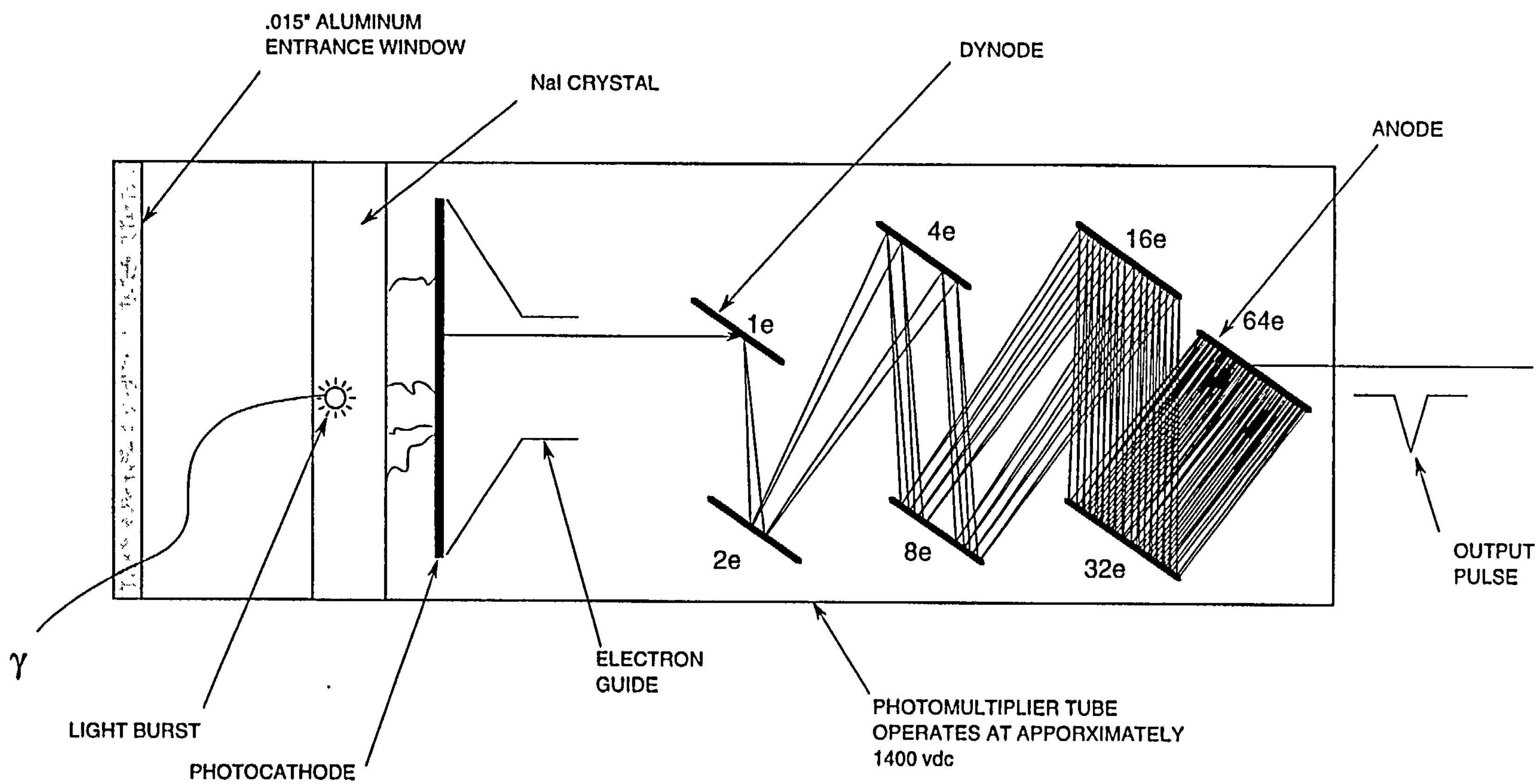

Figure 16-2 Scintillation Detector

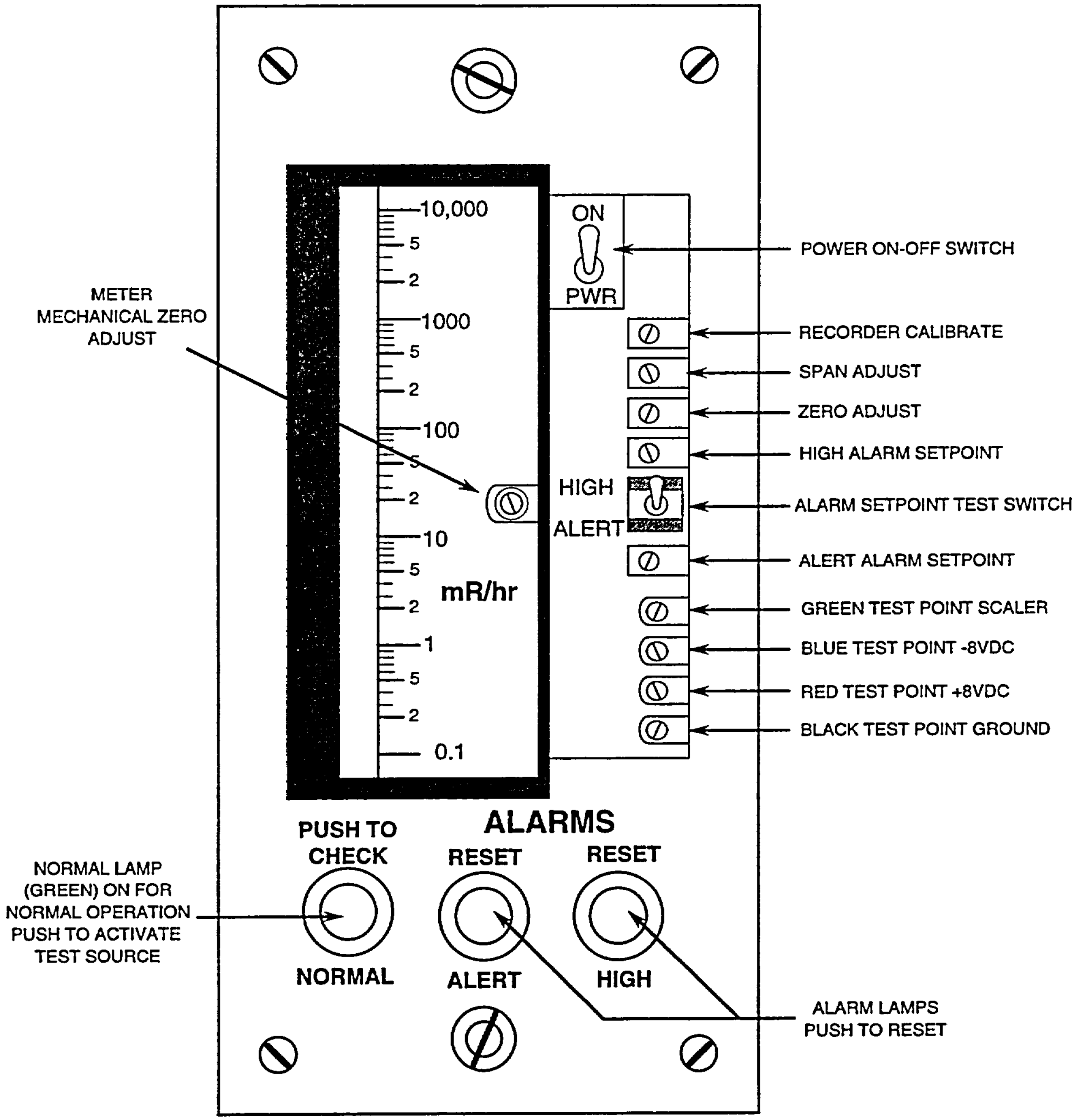

Figure 16-3 Area Radiation Monitor Meter

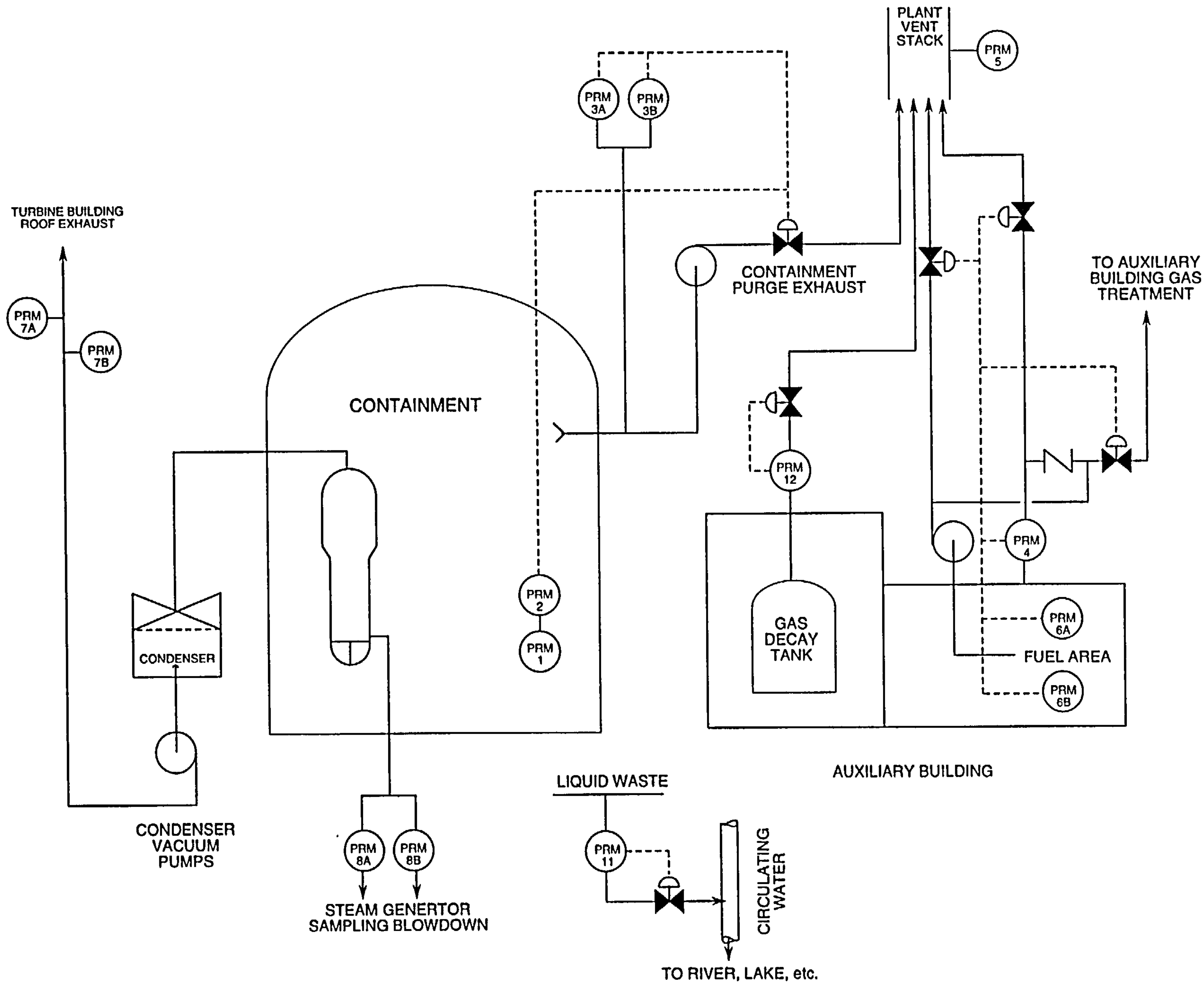

Figure 16-4 Radiation Monitor Locations